Air Force Logistics Management Agency

thinking about Logistics 2009

Selected Readings

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Thinking About Logistics 2009

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Preface

Thinking About Logistics

Defining Logistics

The word logistics entered the American lexicon little more than a century ago. Since that time, professional soldiers, military historians, and military theorists have had a great deal of difficulty agreeing on its precise definition.[1] Even today, the meaning of logistics can be somewhat *fuzzy* in spite of its frequent usage in official publications and lengthy definition in Service and Joint regulations. Historian Stanley Falk describes logistics on two levels. First, at the intermediate level:

> Logistics is essentially moving, supplying, and maintaining military forces. It is basic to the ability of armies, fleets, and air forces to operate—indeed to exist. It involves men and materiel, transportation, quarters, depots, communications, evacuation and hospitalization, personnel replacement, service, and administration.

Second, at a higher level, logistics is:

> … economics of warfare, including industrial mobilization; research and development; funding procurement; recruitment and training; testing; and in effect, practically everything related to military activities besides strategy and tactics.[2]

While there are certainly other definitions of logistics, Falk's encompassing definition and approach provides an ideal backdrop from which to examine and discuss logistics. Today, the term combat support is often used interchangeably with logistics.

Logistics and Warfare

General Mathew B. Ridgway, of World War II fame, once observed, "What throws you in combat is rarely the fact that your tactical scheme was wrong … but that you failed to think through the hard cold facts of logistics." Logistics is the key element in warfare, more so in the 21st century than ever before. Success on the modern battlefield is dictated by how well the commander manages available logistical support. Victories by the United States in major wars (and several minor wars or conflicts) in the 20th century are linked more directly to the ability to mobilize and bring to bear economic and industrial power than any level of strategic or tactical

design. The Gulf War and operations to liberate Iraq further illustrate this point. Long before the Allied offensive could start, professional logisticians had to gather and transport men and materiel and provide for the sustained flow of supplies and equipment that throughout history has made possible the conduct of war. Commanders and their staffs inventoried their stocks, essayed the kind and quantities of equipment and supplies required for operations in the severe desert climate, and coordinated their movement plans with national and international logistics networks. *"The first victory in the Persian Gulf War was getting the forces there and making certain they had what they required to fight* [emphasis added]. Then and only then, would commanders initiate offensive operations."[3] The same may be said of victory in Iraq, although without the massive stockpile of inventory seen during the Gulf War.

In 1904, Secretary of War Elihu Root warned, "Our trouble will never be in raising soldiers. Our trouble will always be the limit of possibility in transporting, clothing, arming, feeding, and caring for our soldiers…."[4] Unfortunately, the historical tendency of both the political and military leadership to neglect logistics activities in peacetime and expand and improve them hastily once conflict has broken out may not be so possible in the future as it has in the past. A declining industrial base, flat or declining defense budgets, force drawdowns, and base closures have all contributed to eliminating or restricting the infrastructure that made rapid expansion possible. Regardless, modern warfare demands huge quantities of fuel, ammunition, food, clothing, and equipment. All these commodities must be produced, purchased, transported, and distributed to military forces. And of course, the means to do this must be sustained.

The End of Brute-Force Logistics

The end of the Cold War and experience gained from the conflicts in Grenada, Panama, and the Persian Gulf essentially brought the era of *brute force* logistics to a close. The traditional practice of using massive quantities of troops and large stockpiles of supplies available in theater to engage sizable hostile forces is obsolete. Additionally, extensive buildup time and lengthy resupply and repair pipelines to sustain forces are unrealistic. The focus of logistics has now shifted toward rapid

movement of small, independent force packages to employ precise combat power anywhere in the world. The rapid change in political dynamics of the world powers, domestic fiscal constraints, and technological advances have rendered the Cold War military strategy and preparation ill-equipped to handle 21st century missions, requirements, and demands.

Logistics Challenges

The US role in the post-Cold War world has changed dramatically. Military forces are no longer dedicated solely to deterring aggression but must respond to and support homeland defense and humanitarian missions. From peacekeeping to feeding starving nations, to conducting counterdrug operations, the military continues to adapt to evolving missions. Logistics infrastructure and processes must evolve continuously to support the new spectrum of demands. The keys to supporting combat operations successfully are robust, responsive, and flexible logistics systems.

Decreases in funding and the drawdown of the US military in the 1990s drove new approaches to logistics support and refinement of the military logistics systems. These fiscal constraints dictated that the military reduce infrastructure, maintain smaller numbers of both inventory and personnel, and find ways to reduce costs without degrading mission capability.

Reduced budgets impact weapons modernization programs in several ways. As dollars decrease, fewer systems can be developed, which increases the importance of decisions made in the acquisition process. The process must develop the most lethal systems while emphasizing reliability and supportability. Therefore, logistics considerations play a more important role than ever in the design, production, and fielding of new systems. Logistics capabilities for supporting future forces require systems to be *smarter* and require less maintenance.

Technology and Logistics

Technology (to include technological change and technological innovation), as a subject, covers a lot of ground and often enjoins heated debate. It has proven to be one of the major tools for dealing with problems, perhaps more so in the 21st century than at any other time in history. However, critics of technology argue that it often causes as many problems as it solves and that the new problems are often far worse than the old ones. Further, they question its validity as a major tool for solving complex problems rooted in ethical, philosophical, political, or other nontechnical areas.[5] These are, by no means, all the criticisms of technology, but they serve to frame the basic objections. The counter argument to these criticisms would answer that technology is not unique in creating new and, often, more difficult problems, while solving old ones. Very much the same criticism could be aimed at all approaches to problem solving. No problem-solving approach yields simple, final answers to the basic problems of humankind.[6] One could even argue that philosophical and other nontechnical approaches have done little when measured against the same standards; they fail just as abjectively as technology.[7] Further, the

fact that technological solutions are inappropriate in certain situations does not mean that technology is always unsuited to problem resolution. Technology cannot be viewed as a separate entity within either the military or society in general. This illusion of discreteness simply does not exist. It is and will remain an integral part of both. The real issue is to recognize that technology is a tool with limitations, and these limitations should be considered in reacting to particular situations. Technology does not offer a *silver bullet* for all situations.

Organizational change should and must accompany technological change if new capabilities are to be exploited. Stephen Rosen, in *Winning the Next War,* points out that innovation does not always result from new technologies. Rather, new technology simply may be used to improve the ability to perform a particular mission.[8] The relationships among technological innovation, fundamental military operations, and changes in concepts and organizations are nonlinear. That is, changes in input may not yield proportionate changes in output or other dynamics.[9]

Significant organizational, intellectual, and technological changes are seen during periods of transition. The major change, however, must be intellectual. Without this, technological change becomes meaningless and organizational change impossible. The US military is now in a period of rapid change. Recent changes—order of magnitude changes—in technology have led to both long-range and strategic planning efforts that integrate current and future technological advances into operational concepts. In the logistics arena, these include Focused Logistics at the Joint level and Agile Combat Support (ACS) within the Air Force. The vision of both these is the ability to fuse information, transportation, and other logistics technologies to provide rapid response, track and shift assets while en route, and deliver tailored logistics packages at all levels of operations or war (strategic, operational, and tactical).[10] This same vision includes enhanced transportation, mobility, and pinpoint delivery systems.[11] The operational forces that must be supported logistically will be smaller and more flexible—emphasizing mobility, speed, and agility. These forces will utilize technological superiority in stealth, precision weapons, surveillance, and dominant battlefield awareness.

Military logistics, at a more fundamental level, is in a period of transition brought about by the evolving information revolution. Many challenges concerning workflow, improving data integrity, and efficient communications still exist. A variety of human and cultural factors still impede full-scale adoption of many new information technologies—complexity and difficulty in the use of some systems, loss of control, changes in fundamental power relationships, uselessness of old skills, and changes in work relationships.[12] Change and instruments of change, as apparent as they seem once implemented, often elude understanding before they enter the mainstream.[13] As an example, Chester Carlson, the inventor of the photocopy machine (often referred to as the Xerox machine) was told by business that his invention was unnecessary because libraries and carbon paper already filled the need. This was a technology that drastically altered the way people approached information, yet finding interested businesses and investors in the beginning proved elusive.

Preface

Any discussion of technology and logistics would be lacking without citing Martin van Crevald. In *Technology and War*, he notes:

> …technology and war operate on a logic which is not only different but actually opposed, nothing is less conducive to victory in war than to wage it on technological principles—an approach which, in the name of operations research, systems analysis or cost/benefit calculation (or obtaining the greatest bang for the buck), treats war merely as an extension of technology. This is not to say … that a country that wishes to retain its military power can in any way afford to neglect technology and the methods that are most appropriate for thinking about it. It does mean, however, that the problem of making technology serve the goals of war is more complex than it is commonly thought to be. The key is that efficiency, far from being simply conducive to effectiveness, can act as the opposite. Hence—and this is a point which cannot be overemphasized—the successful use of technology in war very often means that there is a price to be paid in terms of deliberately *diminishing* efficiency.
>
> Since technology and war operate on a logic which is not only different but actually opposed, the very concept of "technological superiority" is somewhat misleading when applied in the context of war. It is not the technical sophistication of the Swiss pike that defeated the Burgundian knights, but rather the way it meshed with the weapons used by the knights at Laupen, Sempach, and Granson. It was not the intrinsic superiority of the longbow that won the battle of Crécy, but rather the way which it interacted with the equipment employed by the French on that day and at that place. Using technology to acquire greater range, firepower, greater mobility, greater protection, greater whatever is very important and may be critical. Ultimately, however, it is less critical and less important than achieving a close *fit* between one's own technology and that which is fielded by the enemy. The best tactics, it is said, are the so-called *Flaechenund Luecken* (solids and gaps) methods which, although they received their current name from the Germans, are as old as history and are based on bypassing the enemy's strengths while exploiting the weaknesses. Similarly, the best military technology is not that which is *superior* in some absolute sense. Rather it is that which *masks* or neutralizes the other side's strengths, even as it exploits his weaknesses.
>
> The common habit of referring to technology in terms of its capabilities may, when applied within the context of war, do more harm than good. This is not to deny the very great importance of the things that technology can do in war. However, when everything is said and done, those which it cannot do are probably even more important. Here we must seek victory, and here it will take place—although not necessarily in our favor—even when we do not. A good analogy is a pair of cogwheels, where achieving a perfect fit depends not merely on the shape of the teeth but also and, to an equal extent, on that of the spaces which separate them.
>
> In sum, since technology and war operate on a logic that is not only different but actually opposed, the conceptual framework that is useful, even vital, for dealing with the one should not be allowed to interfere with the other. In an age when military budgets, military attitudes, and what passes for military thought often seem centered on technological considerations and even obsessed by them, this distinction is of vital importance. In the words of a famous Hebrew proverb: "The deed accomplishes, what thought began."[14]

Notes

1. George C. Thorpe, *Pure Logistics*, Washington, DC: National Defense University Press, 1987, xi.
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3. Charles R. Shrader, *U.S. Military Logistics, 1607-1991, A Research Guide*, New York, NY: Greenwood Press, 1992, 3.
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6. *Ibid*.
7. Jordan and Lobenstein, 106.
8. Stephen P. Rosen, *Winning the Next War: Innovation and the Modern Military,* Ithaca, New York, NY: Cornell University Press, 1991, 134.
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11. *Ibid*.
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13. Norma R. Klein, "Technology Trends and Logistics: An Interrelational Approach to Tomorrow," *Air Force Journal of Logistics*, Vol XIII, No 2, 36.
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Foreword

Thinking About Logistics

Thinking About Logistics 2009 is a collection of 37 essays and articles—in three sections: Historical Perspective, Contemporary Thought and Issues, and Studies and Analyses—that lets the reader look broadly a variety of logistics areas. Included in the volume is the work of many authors with diverse interests and approaches.

The content of *Thinking About Logistics 2009*, ranging across approximately 10 years, was selected for two basic reasons—to represent the diversity of the ideas and to stimulate thinking. That's what we hope you do as you read the material …think about the challenges. Think about the lessons history offers. Think about why some things work and others do not. Think about problems. Think about organizations. Think about the nature of logistics. Think about fundamental or necessary logistics relationships. Think about the past, present, and future.

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Section One

Historical Perspective

Lieutenant Colonel Andrew W. Hunt, USAF

From Production to Operations: The US Aircraft Industry, 1916-1918

Introduction

It may be difficult to believe, but America's air force has not always been the best in the world. In fact, before American involvement in World War I, the aviation industry in this country was, for all intents and purposes, nonexistent. This is astounding, given that only a decade before, the Wright brothers had made their famous flight. Shortly thereafter (in 1908), they pitched the idea of using their new flying machine for military purposes to Army officials at Fort Meyer, Virginia. Momentum was strong. But after that meeting, where the brothers' idea was met with skepticism, subsequent efforts to increase the use of the airplane in a military role were minimal, at best. The outbreak of the war in 1914 did little to rekindle a fire that had, for the last 6 years, barely flickered. No one was sure how America would get involved in the conflict. As American intervention in the war became more and more likely, politicians and military leaders alike sought to determine where the United States could help the most—and the fastest. Everyone knew that the US Army would send troops, tanks, and other equipment to the front, but an opinion gaining momentum in Washington was that America might prove a more effective ally if it were to provide a combat air force to the European theater.

The role of the airplane in war had evolved quickly, from simple scouting and artillery spotting to aerial troop support and bombing missions. No longer was the airplane a novelty, it was now a military necessity. In an impassioned statement to the US Government in the spring of 1917, French Premier Alexandre Ribot urged the United States to make a sizable contribution to the production and deployment of aircraft in the European theater.[1] Seeing an opportunity to have a greater impact in the war, not only on the battlefield but also above it, the government began a renewed effort to establish a legitimate aircraft production base in the United States.

From Production to Operations: The US Aircraft Industry, 1916-1918

The apathy pervasive in the industry meant that serious obstacles existed. Little had been done to advance the technology of the American airplane to the same level as that of the airplanes flown by other combatants.

Unfortunately, the apathy pervasive in the industry meant that serious obstacles existed. Little had been done to advance the technology of the American airplane to the same level as that of the airplanes flown by other combatants. A limited production base initially proved completely inadequate to the challenge of contributing anything meaningful (in terms of aircraft production) to the war. There was no significant information base from which to draw technical expertise in the construction of these new, military-specific airplanes. And there was no prior experience available to direct and guide those in charge of managing this Herculean task. This was extremely evident in the arena of logistics. Never before had the United States had to plan for a production and movement of this size (especially for a new battlefield instrument), and there had never been an obstacle the size of the Atlantic Ocean to hinder the efforts of planners to sustain such an operation. Nevertheless, failure was not an option. The United States *had* to provide a sufficient (in both capacity and capability) air arm if the Allies were to have any increased chance of winning the war above the trenches. As a member of the newly formed Aircraft Production Board said, "The eagle must win this war."[2] Each area of logistics, from production to repair, presented relatively new challenges to the individuals in Washington and on the Western Front. In as little time as possible (roughly 14 months), an intricate system was established to deploy airplanes and then provide the battlefield logistics support necessary for the Air Service to keep the Allied skies clear.

This article examines the state of the aircraft industry (and the associated logistics issues) before and during American involvement in the First World War. The article is divided into three separate sections. First, there is a discussion of the state of the industry in late 1915 and early 1916, to include existing aircraft, facilities, and production centers. A second section examines the logistics methods used and hurdles faced in attempting an unprecedented rapid mobilization. In this section, the formation of the organizations responsible for forming the Air Service is mentioned briefly. The majority of this section, however, focuses on the trials and tribulations of actual aircraft production, specifically the American version of the British De Haviland (DH)-4. From raw materials to finished goods, the generation process of a satisfactory aerial platform was expensive, untested, and time-consuming. As aircraft were needed in large numbers in minimum time, this process is worth investigating. The lack of an existing infrastructure in the airplane industry meant the production process had no prior model. The third section of the article focuses on the planning and construction of the Liberty engine. Like the DH-4, the production of this powerhouse required logistics efforts unseen prior to 1917.

The *Air Service* Before the Americans Entered the War (1915-1917)

While the war raged in Europe, the US *air force* lay dormant. In 1915, the entire inventory consisted of 55 airplanes, all trainers. Of this astoundingly low number,

General John Pershing, commanding officer of the Army, commented that "51 are obsolete, and the other 4 are obsolescent."[3] Even though the primary need for airplanes was for trainers, it was surprising that the inventory did not include a single combat (bomber or pursuit) plane.[4] (While there were aerial operations in the Mexican campaigns, none was considered a combat mission; airplanes flew observation missions in support of the soldiers on the ground.)

Additionally, the military possessed and operated only two dedicated flying fields: one in Texas and one in New York.[5] In terms of personnel, the Air Corps was just as lacking. Of the 131 officers in this branch of service, only 26 were considered *fully trained,* and not a single member of the US military "had actual combat flying experience."[6]

While the aircraft situation before the United States entered the war was dire, few options were available to correct this problem. In 1915 and 1916, the Curtiss Company was the lone company capable of contributing anything substantial in terms of airplane output. Curtiss was already producing 100 training planes per month for the British.[7] Within a year, the number of contractors the government employed to build airplanes increased to nine companies, tasked to produce 366 planes (of which only 64 were ever delivered).[8]

American Aviation Prepares for War

In late 1916, it was apparent that the United States would soon be a major participant in the war in Europe. As such, it would send its army to fight alongside the British, Italians, and French. But its contribution would not be limited to the role of the foot soldier. With louder and louder voices, the Allies embroiled in the conflict across the ocean urged the United States to contribute a sizable air arm. As the United States was the pioneering nation in the frontier of flight, this was hardly unreasonable. However, as mentioned earlier (and a statement that will be a recurring theme), the apathy in American aviation made this request a difficult one. Before 1917, US civil aviation activities were not at a level that could be considered significant.[9] "America, with the apathy of peace, had been outdistanced by the billigerents in the science of aviation."[10]

While the aircraft situation before the United States entered the war was dire, few options were available to correct this problem.

Formation of National Committee on Aeronautics and the Aircraft Production Board

The first signs of life in the military aviation sector surfaced in late winter of 1917. On 5 February, officials in the air arm of the army decided to prepare an initial estimate on the aviation requirements needed to support an organization of regulars, volunteers, and the National Guard. Initial dollar amounts neared a staggering $49M.[11] Again, the capacity of the industrial sector to handle these requests was unknown. In the first few months of 1917, the number of contractors employed by the government stood at 11, and nearly 300 planes were on order.[12] For the first time, thought was given to managing the production and acquisition of these materials.

From Production to Operations: The US Aircraft Industry, 1916-1918

The National Committee on Aeronautics was established in March 1917; its mission was to bring together the manufacturing sector and the government since there was a noted "lack of cohesion."[13] This organization was designed to prevent duplication of efforts and keep costs under control. The committee, headed by noted paleontologist Dr Charles D. Walcott, recognized the absolute lack of airplane manufacturing capability and suggested, to speed up production and mobilization, a standardized training plane for use by both the Army and the Navy be adopted as soon as possible.[14]

Since the airplane production sector was so far behind, the APB proposed a deal with the French that would allow the military to make a more immediate impact in the air war in Europe.

In April 1917, the government formed the Aircraft Production Board (APB) to oversee the production plans and projections for the Army aviation sector. This organization was the focal point for all military aircraft production and was solely responsible for ensuring that the United States could field a viable air contingent. Headed by Howard E. Coffin, an automobile manufacturer from Detroit, the APB began its crusade on 12 April (6 days after America formally entered the war), with the announcement of a 3-year production plan: 3,700 aircraft in 1918, 6,000 aircraft in 1919, and from 9,000 to 10,000 aircraft for 1920.[15] Initially, the main focus of the Board was the production of trainers. The rationale behind this decision was that there was little or no knowledge of battle planes in this country and that the gathering of information over the next 6 months (April-October 1917) from the Allies would slow production to the extent that the output realized by manufacturers would be of little use in the war effort.[16]

Since the airplane production sector was so far behind, the APB proposed a deal with the French that would allow the military to make a more immediate impact in the air war in Europe. In May 1917, the United States proposed a 16,500-ton shipment of men and materials to France in exchange for airplanes, motors, and land for airfields.[17] In August of the same year, the deal was revised to read that France would send 5,000 planes and 8,500 engines in return for tools and materials.[18] This deal seemed feasible, as the United States had greater quantities of human and materiel resources, while the Allies had a greater capability to produce combat-ready aircraft.[19] This early reliance on the French would be a pervasive theme throughout the war.

American Intervention Requested

In the summer of 1917, the French and British governments applied the most direct pressure to the American aviation sector. In a meeting between French Premier Rene Viviani and Britain's Lord Arthur Balfour, the common sentiment was that the United States could do more to help the Allied effort by "sending a powerful air force to the Western Front in time to participate in the 1918 campaign."[20] Soon after that meeting, a statement issued by Premier Ribot on 26 May urged the United States to furnish a flying corps of 4,500 aircraft, 5,000 pilots, and 50, 000 mechanics. After this initial requirement, Ribot requested that there be 2,000 planes and 4,000 motors built in the American factories each month until early 1918.[21] Ribot's request may

have had some extreme outside influence. It is rumored that the impetus for this proposed plan may have come from Lieutenant Colonel William "Billy" Mitchell.[22] Amazingly, these requests were deemed by the Aircraft Production Board to be attainable.

Many people echoed the sentiments for American air involvement. Secretary of War Newton Baker said that the formation of an air arm "seems …the most effective way in which to exert America's forces at once in telling fashion."[23] Orville Wright, still an active participant in the aircraft industry, commented that if the Allies have a sufficient number of airplanes to keep the enemy planes back, and their "eyes can be put out—it will be possible to end this war."[24]

Now that a crude production schedule was in place, the military began to tackle the immense logistics effort required to support this massive mobilization. Not only were the engineers and manufacturers under a severe time constraint, but there was also no experience in the production of combat planes to make this process any easier. Unfortunately, for the United States, the Army had not sent observers to Europe to get the necessary technical information for the construction of these aircraft.[25] "Much of it [the project] had to be drafted in the dark," and there was a "supreme need for haste."[26]

The journey of aircraft production began on 24 July 1917, with the passing of the Aviation Act in Washington. This legislation provided $640M (although this number would decrease dramatically in the coming year) for research and design, supplies and manufacturing, and procurement of airplanes.[27] The initial projections for having 2,500 operational, domestically built aircraft by 1 January 1918 available for training were deemed "totally within reach … and immediate efforts were taken to build 500 training machines."[28]

Perhaps one of the biggest obstacles facing the military in the pursuit of airplane production was the lack of experience in the logistics arena.

Obstacles to Initial Production—Inexperience and Raw Materials

The ability of a nation to produce and procure materiel is key to supporting military operations. General Carter Magruder, a prominent army logistician, noted that, for a nation to be successful in a military campaign, its domestic production must be equal to the expected consumption in all theaters.[29] James Huston, a noted military historian, added that, in the realm of production and fielding of new weapons of war, there are concerns in the production sector. He observed that a new weapon (or piece of equipment) may incur "delay(s) in production," and experience supply difficulties. Put these two thoughts together, and it's clear that building an air force from scratch was going to be extremely difficult.

Perhaps one of the biggest obstacles facing the military in the pursuit of airplane production was the lack of experience in the logistics arena. No one involved had any appreciable expertise in this area, and the events that transpired in late summer of 1917 brought this fact to light. The lack of experience nearly derailed the initial efforts of the Army to field a viable air arm before it even began. Other American

From Production to Operations: The US Aircraft Industry, 1916-1918

industries had benefited from the early years of the war. The Allies had turned to the United States for assistance in the supply of ammunition (among other things), but they never asked for help in producing airplanes.[30] As a result, the airplane industry was nowhere near capable of responding to the initial requests, and even the work done since America entered the war had been "wholly inadequate."[31] The procurement of raw materials for aircraft production was a huge roadblock that faced the men responsible for building these machines. This issue would prove costly and difficult.

Raw materials are the first key to production and, therefore to any logistics operation.

Raw Materials

Raw materials are the first key to production and, therefore to any logistics operation. Huston notes that the availability of raw materials for an item (and the subsequent ease of production for that item) is as important as the battlefield performance of that item.[32] Little thought was given to the fact that the lack of any material, whether major or minor, could lead to the grounding of any production process. As one observer noted, "no one ever thought that the production programme … could be held up by the lack of small items, such as acetate lime for aircraft doping."[33] To ensure the availability of these necessary materials, the government decided that intervention was necessary. The government decided that it must manage and finance these different industries.

The WWI airplane was constructed mainly of wood and linen held together by a series of wires, stitches, and adhesives. The wood used in the production of the airplane had to be lightweight, as the power of the available engines was not sufficient to lift much weight. At the same time, the wood had to be flexible and durable to withstand the poundings administered by both the wind and the ground (landings could be quite rough). Engineers determined that spruce would be the best wood, as it was the "toughest of the softwood."[34] The difficulty facing the government was the collection and processing of this raw material and its delivery to the necessary production plants. The spruce reserves were located in the remote forests of the Pacific Northwest. Access to that area was limited as the roads were often impassable. The government embarked on a large lumberjacking operation, sending approximately 15,000 troops to harvest the valuable wood in the forests of Oregon. This was an unplanned deployment, as no one could have predicted that troops would be used to collect raw materials.

Since spruce was deemed perfect for aircraft production, the government sought to keep it out of the hands of the Central Powers, and the APB announced that "all spruce would be bought by the government."[35] Here, the government exercised its right to act in the interest of national security by basically monopolizing the spruce industry, setting the price that the loggers and lumberjacks could charge per long ton of wood. The spruce was milled (using roughly 4.5 percent of each tree cut—try getting away with that today) and sent by truck to the production plants for further refinement to make it suitable for airplane usage.

Obviously, wood was a main concern, but the availability of linens (for wings and fuselages) and dopes (a material used to coat the wings to render them flame-resistant, waterproof, and tight) was also in question. The need for these two materials was immense. In 1918 alone, the Air Service requested nearly 10 million yards of linen and 204,000 gallons of aircraft dope. The production of these materials was already at the maximum levels available. "Supply could not be increased by existing plants nor by building new plants" due to the lack of precious wood.[36] Another example of the shortage of raw materials was the lack of castor oil, a lubricant used in aircraft systems. To combat this problem, the United States actually imported castor beans from Asia to seed farmland in this country, thereby creating raw materials.[37] The process of collecting, transporting, and processing these resources was an important hurdle facing the government in 1917. Even with the active participation of the government, many asserted that "satisfactory aviation material would not be available until 1918."[38]

Aircraft Production

As mentioned earlier, when the United States entered the war, the initial need for domestic aircraft production was solely to fill the requirement for training aircraft. The Curtiss Company and the Standard Aero Company, with the production of the JN-4 *Jenny* and the SJ-1, respectively, adequately fulfilled this need. However, the real challenge rested in the ability of the American industry to produce combat-specific aircraft in time to make them available for the 1918 campaign. At the time, there were four major problems facing the United States in this venture. First, there was no existing knowledge of battle planes or their construction. As noted earlier, the US inventory did not have a single battle plane at the time the United States entered the war. Arthur Sweetser said, "At the outbreak of the war, no one in this country had any knowledge of what a battle plane was." Second (again a prevalent theme), there was a shortage of any appreciable manufacturing and engineering facilities, and capacity prohibited the advancement of airplane technology. Third, the United States was geographically removed from the fighting, which prevented both timely communications and the expedient flow of information with the combatants on front. Finally, no one in the industry was prepared to handle the intricate nature of the problems that would undoubtedly surface with the employment of these new machines.

The real challenge rested in the ability of the American industry to produce combat-specific aircraft in time to make them available for the 1918 campaign.

Specifically addressing the first area of concern, the government sent observers to Europe to obtain the necessary technical data to begin construction of the airplanes. The representatives, led by Major R. C. Bolling, arrived in Europe nearly 3 months after the United States entered the war. As a result, combat aircraft production efforts could not begin until early summer of 1917.[39] Still, the entire production process would be trial and error, with most improvements made after "bitter experience and disappointments."[40] The lack of manufacturing, distance from

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Originally, the military decided that the construction of combat planes would focus on an American redesign of the immensely capable and extremely popular Spad fighter. However, the life of the single-place (single seat) plane produced in the United States was short-lived.

the front, and inability to solve technical problems all surfaced in the determination of what planes the United States would actually produce.

Originally, the military decided that the construction of combat planes would focus on an American redesign of the immensely capable and extremely popular Spad fighter. However, the life of the single-place (single seat) plane produced in the United States was short-lived. On 15 December 1917, Pershing ordered that production focus on a two-seat variety of airplane and that the production of the single seat planes be left to the Europeans. Subsequently, the reproduction of the Spad was canceled.[42] The military then decided that the British DH-4, a daytime reconnaissance and bomber platform, was to be the focal point of the American Air Service and its production efforts.

The production of the DH-4 was delayed until August 1917, since a model had not yet reached the United States. The model arrived in Dayton, Ohio, on the 26th of the month, and was available for use as a basis for production.[42] The production facilities housing the DH-4 operations were literally built as the plane was constructed. In 2 months, the first DH-4 was rolled off the assembly line and made its first test flight on 28 October 1917. Powered by a Liberty engine, the plane passed all initial tests and was now ready for mass production.

After the successful test flight of the DH-4, the APB awarded a contract for 2,000 aircraft to the Dayton-Wright Company. Initial projections for aircraft production showed that 1,475 aircraft would be ready by 3 January 1918. However, nearly 3 weeks after that projected completion date, the DH-4's production life had just started. The problems of production were not due to a lack of raw materials, as government assistance ensured the requirements were met, but to the continued lack of experience and technical knowledge in the area of production. (The manufacturing processes used in the United States were markedly different than those used in Europe. The United States mastered the assembly line technique, best suited for items that could be made the same way over and over again. In Europe, the production process was highly specialized, where each item was manufactured in whole, one item at a time.)

It was not until 5 February 1918 that the first operational DH-4 aircraft left the Wright plant and arrived in Hoboken, New Jersey. On 15 March, the aircraft was packed aboard a steamer destined for France.[43] On 8 April, the first US-built DH-4 arrived in France. Nearly a month later, the aircraft flew its maiden voyage, armed as a combat plane should be. Although the results of the test flight were deemed satisfactory, certain changes had to be made to the airframe, which further slowed production and deployment. Specifically, the munitions stations on the aircraft were of British design and were not capable of holding US ammunition. New bomb racks were needed. These were easy corrections, and by the end of 1918, the DH-4 was in "appreciable production."[44] A fully-armed DH-4 consisted of two .30-caliber Marlin machine guns in the nose and two .30-caliber Lewis machine guns in the rear, plus 220 pounds of bombs. By the spring of 1919, it was a viable aerial addition to the

Allied efforts. The production rate of the DH-4 was unrivaled for the time period. Said Secretary Ryan, "We built more airplanes from month to month from the time we began than any other nation in the war built from the time it began."[45]

While mass production of the DH-4 was ultimately successful, aircraft production in the United States included other efforts. The government redesigned both the Italian-designed Caproni heavy bomber and the British Handley-Page bomber. Three Capronis were ultimately assembled, while the Handley-Page never progressed past the prototype stage until after the war.

The Liberty Engine

Although the DH-4 is a remarkable example of time-constrained manufacturing of an unproven commodity, the simple fact is that a plane will not fly without a powerplant. In fact, the size of an air force is contingent upon how many quality motors it can acquire or produce.[46] Coinciding with the development of the combat airplane was the aggressive production of the Liberty engine. So named to represent the principle by which it was constructed, the Liberty engine was the shining achievement of American industry during World War I. The Liberty's road was not smooth, as the same pitfalls that slowed production of the DH-4 were also present in the engine-manufacturing sector. At the time of American intervention, four separate manufacturers were capable of building and had built airplane engines. However, since there were no combat planes in the US arsenal, all engines previously constructed were used for training planes only. Therefore, they lacked the power and lightweight characteristics required for use in bombers and pursuit planes. The major challenge, then, was to accomplish two goals: (1) enable the existing manufacturers to increase their capacity to a sufficient level that would allow them to continue producing these engines to meet the growing need of the aviation training program and (2) require the manufacturers to design and build an engine capable of supplying the necessary power to lift the heavier aircraft. By the end of 1917, the first part of the challenge was met. The Curtiss OX5 and the Hall-Scott A7A were produced in sufficient numbers to meet all training requirements. The second part of the challenge would be more difficult to accomplish.

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Since an engine takes nearly twice as long to roll through production as an airplane, it is no surprise that brainstorming designs for a new engine occurred shortly after the United States entered the war. In May, designers and engineers met in Washington, DC, determined to leave with the plans for a new, standardized motor. Unlike their decision to redesign the DH-4, the government decided that this engine should be domestically designed and produced, as the design differences among engines would not be easily reconcilable. The goal for this new motor was to remedy all repair problems overseas by using a set of standardized, interchangeable parts, while allowing for a marked increase in horsepower over models already available. After only 4 days in Washington, the plans for the Liberty motor were completed. The motor was to be an 8-cylinder, capable of producing 400 horsepower. Of utmost

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Despite these roadblocks, production of the Liberty engine reached 15,572 engines by the end of the war, with production reaching an astounding rate of 150 engines per working day at the height of production.

importance was that the Liberty would have a single stream of spare parts to facilitate the inevitable repair needs overseas.[47]

In determining who would build the motor, the government turned to the automobile industry, which had the existing technology base to begin the task. Lincoln, Packard, and Nordyke and Marmon were selected for the contract, which was awarded on a cost-plus basis; the contractor would be reimbursed for their costs, plus some portion for incentives.[48] The first engine was assembled at the Packard Plant in Detroit and sent to Washington for testing on 3 July 1917. Shortly thereafter, the development and testing of a 12-cylinder version of the engine, designed to better fit the DH-4 aircraft on the production lines, were completed.

As promising as the future of this new engine was, there were still major problems in the production process. As with the DH-4, the projections on production for 1918 were overly optimistic, and the production dates were pushed back repeatedly. The plan was to have more than 9,400 motors produced by the beginning of June 1918. In actuality, the number available by the end of May 1918 was a little more than 1,100.[49] These problems in production resulted from (as in the aircraft industry) the total inexperience in the manufacturing of this type of machine in both large numbers and in a short time. Those in Europe believed the American method of standardized production could not be applied to the construction of a precise instrument such as an airplane engine.[50] Interestingly, the construction of the airplane engine placed more demands on the manufacturers than did the automobile engine. Manufacturers were forced to expand their capacity (facilities and so forth) to handle these demands.

Manufacturers had to design new machines and tools to build the engines. This took time. In addition, obtaining materials for the production of this engine was not easy. The Liberty 12 was roughly 25 percent lighter than a 12-cylinder automobile engine, so the materials needed for construction of the Liberty were different than those found in the typical automobile of the day.

Despite these roadblocks, production of the Liberty engine reached 15,572 engines by the end of the war, with production reaching an astounding rate of 150 engines per working day at the height of production.[51] The engine was popular with the Allies, as it possessed more power than any other aircraft engine available in the theater. As such, the demand for Liberty engines was "far greater than the Air Service's demands alone."[52] Italy ordered 3,000, the British ordered 300, and France requested a number of engines as well. In terms of raw numbers at the time of the armistice, the production of the Liberty engine has "never been remotely touched in the production of any like complex mechanism."[53]

Transportation

While the production developments of the DH-4 and the Liberty engine were of paramount importance, logistically speaking, nothing can lose a war faster than inadequate transportation. Without the means to get the raw materials from the source to the manufacturers and likewise the finished product overseas, all the efforts by

the industrial sector would not matter. It is likely that the transportation infrastructure of the United States was never tested as it was from 1917 to 1918.

The government realized quickly that transportation must be made available and that those resources were scarce in the country already. As the production tempo increased throughout 1917, the means of transporting aircraft, engines, men, and materiel had to be made accessible. Therefore, in December 1917, the War Department established the Inland Traffic Service. This organization immediately seized the existing railroads and designated them for war use only. [54]

Domestic transportation was only half the challenge facing both the airplane and engine manufacturers and the military. Timely delivery of the planes and the materiel to support them was still unproven. Ocean transportation was the lone option, and in a resurfacing common theme, the United States lacked the capacity for this logistics area. Also, the United States had never attempted to ship instruments as complex and delicate as these new planes and motors. Whether or not they would stand up to the rigors of transoceanic shipping was unanswered.

In 1916, the United States accounted for less than 6 percent of the world's 35 million tons of shipping (in terms of vessels).[55] Efforts were made to charter merchant marine ships to increase the shipping capacity of the United States. It was not until 3 years into the war that the United States chartered seven ships in the fleet dedicated to the movement of materiel. By the end of the war, the maritime transport fleet was capable of shipping 2,310 deadweight tons.[56] The initial lack of tonnage not only hindered the delivery of aircraft and engines to the European theater but also complicated domestic port operations. The major ports of embarkation (Hoboken, Brooklyn, and Newport News) were choked with materiel waiting to be shipped, often with no ship to haul it. As a result, US reliance on foreign shipping was prevalent throughout the war. These port facilities ran at or near peak capacity throughout the war. From August 1917 to the cessation of hostilities, nearly 2,000 tons of various materials left American ports daily in support of the war effort.[55] Tonnage shipped to support the aviation corps in Europe totaled 61,000 short tons. Not included in this total are the quartermaster and engineer supplies used by the aviation corps (to include clothes, food, rail improvements, and others).

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Summary

The prewar environment seriously hindered the initial mobilization of the aircraft and engine production industries. According to established logistics principles, the initial industrial capacity of a nation is one key to conducting successful operations. At no time before the war did the United States possess the required reserves needed to supply an air arm until the production in this country reached adequate levels. This lack of reserves prohibited more timely entry into the conflict, as there were no means from which to fill "unforecasted theater requirements." In addition, the initial planning for production was far too idealistic to be feasible, given that there was little or no prior experience in this field of manufacturing. From a planning

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standpoint, the ability to determine what equipment was needed to fill existing (or planned) requirements was immature, as the planning for such operations was late in coming. Even as the production of both aircraft and engines improved, the level of production reached the level of consumption only at the tail end of the conflict.[58]

The domestic transportation system was vital to the success of the US mobilization and deployment of the Air Service in an efficient manner. In 1917, the domestic transportation system in the United States was entirely adequate for supporting the mobilization effort. A nation's transportation system is key in determining the ability of a nation to conduct efficient operations. If the transportation system can be developed, or is in place to support the necessary force requirements, then the rest of the logistics system can be brought in line in time to be of value.[59] While the logging operations in the Pacific Northwest encountered problems in road conditions and weather, the ability of manufacturers to send the finished goods to the ports was, on the whole, satisfactory. The government's involvement in railroad operations (the Inland Traffic Service) provided the military with the means to transport large amounts of men and materiel in a timely manner. Overseas shipping capabilities lacked, initially, but were soon made sufficient through appropriation of a larger fleet and international cooperation. By the end of the war, the techniques used to deliver troops and cargo were among the best available.

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Roger G. Miller, PhD, DAF

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Royal Flying Corps and Air Service Cooperation in Maintenance Training During World War I

Little need exists here to detail the size, strength, and capability of the US Army at the time the United States declared war on the Central Powers in April 1917. Simply put, in every way possible, the United States was incapable of sending a modern army to fight in Europe. A British military mission that reached Washington, DC a few weeks after the declaration accurately summarized the situation in four laconic, well-chosen words: "They are quite unprepared."[1] Seldom has the British talent for understatement been more appropriate. This situation, especially in the eyes of British and French leaders, would be complicated over the next year by the American determination to field a separate, independent army and stubborn refusal to *amalgamate* with the Allied armies.[2] We could spend hours discussing the controversy over amalgamation, but suffice it to say that Secretary of War Newton Baker's instructions to the commander of the American Expeditionary Force (AEF), General John J. Pershing, issued on 26 May 1917, were clear and firm: "In military operations … you are directed to cooperate with the forces of the other countries employed against the enemy, but in so doing, the underlying idea must be kept in view that the forces of the United States are a separate and distinct component of the combined forces, the identity of which must be preserved."[3] And, as European leaders would soon discover, probably no American general between "Mad" Anthony Wayne and "Stormin" Norman Schwartzkoff could be determined more relentlessly to follow instructions—especially those he agreed with—than "Black Jack" Pershing.[4] Thus, the essential question was reduced to how best to organize, train, equip, and deploy an independent army, starting from almost nothing. The answer, readily apparent to all competent observers, was that a timely American presence on the Western Front could be attained only through extraordinary assistance from the Allied powers.

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The Bolling Mission identified British aircraft for production in the United States with a couple of exceptions, notably the Italian Caproni bomber and French SPAD pursuit. Among the British aircraft selected were the Royal Aircraft Factory SE-5A, the Bristol F2B, the Handley Page 0/400, and the De Havilland DH-4. This effort turned into a major fiasco, however. Differences between European handcrafted manufacturing and American assembly line production by unskilled labor hampered the American program from the beginning.

Since the United States would receive the vast majority of its modern war materials from France, the AEF would be assembled and learn its trade in the heart of France, and the Americans would take their place in the trenches on the eastern part of the Western Front, distant from the British army, it was logical that much of its preparation and training would be in French hands. Where ground warfare was concerned, this logic pretty much held true. When it came to aviation, however, the story was a good bit different. Despite the fact that the Air Service, AEF[5] ultimately would accept more than 4,800 aircraft from the French and less than 300 from the British and despite the establishment of aviation instruction centers throughout France, the US Army turned to the Royal Flying Corps (RFC)[6] in its preparations for combat in the air and, in doing so, began a tradition of mutual cooperation between the Royal Air Force and the US Air Force that has endured on many fields of conflict.[7]

Several reasons underlay this development. Most important, undoubtedly, was the common language and heritage. The close presence of Canada and the role it played in the RFC training program offers another reason. Still another was the compatibility of British methods. One suspects, for example, that the British phased system of flight instruction and RFC stress on disciplined air tactics appealed more than the French *Roleur* system and emphasis on individual flying, though both systems were used. And one also must remember the affinity that quickly developed during the war among British air leaders like David Henderson, Lord Tiverton, and Sir Hugh Trenchard with Air Service leaders like Benjamin D. Foulois, Mason Patrick, and Henry H. Arnold, not to mention a persistent gadfly, who haunted higher military circles, named William "Billy" Mitchell.[8]

The story of US combat aircraft production is well-known. The Bolling Mission[9] identified British aircraft for production in the United States with a couple of exceptions, notably the Italian Caproni bomber and French SPAD pursuit. Among the British aircraft selected were the Royal Aircraft Factory SE-5A, the Bristol F2B, the Handley Page 0/400, and the De Havilland DH-4. This effort turned into a major fiasco, however. Differences between European handcrafted manufacturing and American assembly line production by unskilled labor hampered the American program from the beginning. The SE-5 program, for example, was complicated by the arrival of an incomplete sample aircraft from England, along with plans and drawings that mixed parts from three different versions of the aircraft. Only one was completed before the program was canceled. Likewise, the effort to stuff the massive 400 hp Liberty engine into the frame of the Bristol fighter failed, and three of the overpowered aircraft crashed, killing two crews. This program was also canceled. The Handley-Page program was only a bit more successful, and complete subassemblies for 100 of the huge bombers were shipped to England. None arrived in time for assembly and operational service. Only the DH–4 program yielded aircraft. Ultimately, some 1,440 Liberty-powered DH–4s reached France, but the frame was too weak to allow the Liberty to be run at full throttle, and the pressurized fuel tank between the pilot and observer gave the aircraft the reputation of being a *flamer*.[10]

In the case of pilots, Americans joined the Royal Flying Corps by several different routes. Many crossed the border into Canada as individuals and found their way into the Royal Flying Corps, which was willing to turn a blind eye to the citizenship of suitable volunteers. More than 300 airmen entered the Royal Flying Corps through this route. Another group of Americans comprised the Oxford Group of 204 Air Service cadets sent overseas in August and September 1917. Originally destined for Italy, they were diverted to the ground school at Oxford University, went through the RFC flying training program, and joined British squadrons on the Western Front. Third, the Toronto Group included 300 cadets and 800 enlisted persons sent to Canada for training as a foundation for ten US squadrons, eight of which were formed and sent to Europe. Finally, at least 137 additional individual Americans filtered though the British training system and ultimately were posted to the Royal Flying Corps or were sent through Issoudun as replacements for Air Service units. Ultimately, somewhere between 900 and 1,100 US citizens flew for the Royal Flying Corps, filling a huge gap in British ranks, before most transferred to the Air Service, AEF, bringing much-needed experience.[11]

The Air Service, AEF basic doctrine and operational practices were taken mostly from the Royal Flying Corps. Billy Mitchell, in France as an air observer when the United States declared war, spent several days with Trenchard, RFC Commander, touring British facilities, observing operations, and absorbing Trenchard's deep commitment to offensive operations as the bedrock of air. Subsequently, Mitchell contributed to these attributes during the St Mihiel offensive from 12 to 16 September, during which he amassed more than 1,481 Allied and US aircraft and hurled them like a mailed fist against the enemy.[12] Mitchell's stress on concentrating his air assets had a permanent impact on Air Service doctrine. In historian Tami Davis Biddle's words, "His views, reinforced by the apparent success of the autumn campaigns, would establish the principle of concentration as aerial dogma in the United States."[13] This dogma, combined with Trenchard's emphasis on the offensive, became a trademark of the American way of air warfare.

The British also guided Air Service concepts of strategic bombardment. In November 1917, Major Edgar S. Gorrell presented the new Air Service, AEF, Commander, General Foulois,[14] with a plan for bombing Germany, the main body of which was an almost verbatim copy of Tiverton's 3 September 1917 plan for long-range bombing. And later, Gorrell produced an essay, "The Future Role of American Bombardment Aviation," which included segments of Trenchard's paper on "Long-Distance Bombing" written in November 1917.[15] The two British papers contributed significantly to the doctrine of high-altitude, daylight bombardment of military and industrial targets that characterized US Army Air Forces operations during World War II and US Air Force doctrinal thinking today.

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These are just a few examples of the impact of the close relationship between the veteran Royal Flying Corps and neophyte Air Service during World War I. Another example can be seen in the development of *maintenance* training or, what we would

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call today, *technical* training for enlisted personnel, which, mundane as the subject seems on the surface, is an absolute necessity in the establishment of a modern, professional air force. The Air Service maintenance training effort during World War I, however, began late, and its evolution was chaotic at best before a reasonably defined program began to emerge toward the end of the war. We need to examine this chaos a bit.

To gain an understanding of this development, one must be aware of a significant point. During World War I, the US Army essentially built two separate and different air forces—the first, a training air force in the continental United States; the second, a combination training and combat air force in Europe. A comparison of the chaotic development of maintenance training by the Air Service in the United States with the more logical development of maintenance training by the Air Service, AEF in France—though it was still something less than a smooth process—indicates the importance of the Royal Flying Corps and Air Service, AEF relationship to US combat capability.

During World War I, the US Army essentially built two separate and different air forces—the first, a training air force in the continental United States; the second, a combination training and combat air force in Europe.

It says a lot that the United States declared war on 1 April 1917, received the Ribot cable[16] from France on 24 May, and passed a bill authorizing $640M for aviation on 14 July, but that the Air Service did not get around to addressing the need for a formal maintenance training program until October. Until then, the Air Service largely *winged it* where training was concerned. During the first months of the war, it managed to identify and secure a reasonable number of men who either had—or at least claimed to have—some experience with machinery and some mechanical expertise. These men formed the backbone of the early aero squadrons and enabled army aviation to expand. Tested and classified according to their experience and aptitude, *trade tested* in the vernacular of the day, these men learned on the job and enabled army aviation to expand rapidly without developing formal training for mechanics and technicians.[17]

While many of the enlisted men had mechanical experience and could learn on the job from the few experienced personnel available, this approach was not economical at best and useless at worst, as large numbers of inexperienced people entered the service. And it was apparent that even the most knowledgeable mechanics needed training on the peculiarities of aviation engines and airframes. Some knowledge and skill was transferable from civilian jobs, and experienced men could adapt easily. Automobile engine mechanics, for example, could learn aero engines without great difficulty, and wood workers would have little trouble working with airframes. Greater problems were posed by specialists such as sheet metal workers, welders, and tinsmiths who were in short supply. Finally, individuals experienced with skills peculiar to aviation, such as propeller makers, were extremely rare, and drafting the few available would hamper aircraft production. Everything pointed toward the need for an extensive technical training program, but this took time to develop.

Mechanics who made up the earliest squadrons mostly learned through on-the-job training at the various flying fields. Such instruction, however, tended to be haphazard and superficial, especially since, thanks to the shortage of construction

troops, most of the early squadron personnel also had to construct barracks, hangars, administrative buildings, and other airfield infrastructure in addition to accomplishing other duties. The Air Service did its best, even publishing in August 1917 a training manual that prescribed a 10-week, on-the-job course of practical instruction in electricity, airplanes, gasoline engines, office work, and telegraphy.[18] This attempt to standardize had merit, but ad hoc, on-the-job training programs were not going to meet expanding Army aviation requirements.

In October 1917, the Air Service turned to private industry for assistance, asking a number of civilian factories to admit enlisted personnel and train them in several specialties where severe shortages existed. This approach had a number of advantages. Enlisted personnel would get extensive training from experienced civilian technicians, while the factories would benefit from the influx, even if temporary, of trainable, largely enthusiastic workers who did not have to be paid by the company. The first 25 enlisted men joined an oxyacetylene company on 11 November 1917 for a 3-week course on welding. By the end of the month, an additional 300 or more men had entered companies where they learned 14 different technical specialties. Pleased with the success of the initial courses, the Air Service extended the program on 15 January to the aircraft, aviation engine, and tire industries. In all, more than 30 companies eventually took part in this program, training more than 2,000 mechanics and specialists.[19]

About the same time, winter closed the flying training programs at Chanute, Hazelhurst, Scott, Selfridge, and Wilbur Wright Fields. On 1 November 1917, Air Service officials decided to use these facilities for technical instruction. The Air Service advertised for experienced personnel from industry for instructors. Seventeen applicants became officers, 48 received enlisted rank, and 5 became aviator *mechanicians*. They then received 3 weeks of military training at Selfridge Field. The five schools opened on 1 January 1918 with about 315 students, but some slippage took place between plans and performance. From the first, the five schools were hampered by a shortage of instructors and equipment, the severe winter weather, and a measles epidemic. By the time they ceased operation on 1 April 1918, however, these fields had produced 574 engine and 1,120 airplane mechanics, 939 motor transport specialists, and 30 welders.[20]

October 1917, the Air Service turned to private industry for assistance, asking a number of civilian factories to admit enlisted personnel and train them in several specialties where severe shortages existed.

In December 1917, Air Service planners explored the expansion of maintenance and specialist training through civilian vocational schools. A detachment of enlisted students arrived at the Dunwoody Industrial Institute in St Paul, Minnesota, on 10 December. The initial courses proved excellent, and on 1 January 1918, the Liberty Engine Ignition School opened under the supervision of five of Dunwoody Institute's best instructors. Subsequently, the Institute taught courses that ranged from aircraft and motor maintenance to instrument repair. Additional courses opened at the Carnegie Institute of Technology in Washington, DC on 25 January for coppersmiths, blacksmiths, and motor and aircraft repairmen; at the Pratt Industries, in Brooklyn, New York, on 18 March for carpenters, cabinetmakers, and motor mechanics; and at the David Rankin School of Mechanical Arts in St Louis on 1 March for carpenters, blacksmiths, electricians, metal workers, propeller specialists, and motor mechanics.

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The use of vocational schools proved highly successful, and the Air Service soon incorporated the training at St Paul as a permanent part of its wartime technical training program.[21]

Finally, in mid-November, the Air Service established the Enlisted Mechanics Training Department at Kelly Field near San Antonio, Texas. Initially, this effort bordered on farce. Kelly authorities designed a program for 320 men and set it up in eight hangar tents, each with an aircraft, engine, and instructor. Three days later, a Texas *norther* blew everything down. The officials immediately reestablished the program in two metal hangars, but then no students came. The Kelly Field commander appealed to the commander of the US Army's Southern Department, who ordered every squadron forming at Kelly to furnish a cadre of trainees. The squadrons immediately furnished 3,000 men who, first, were not the best men in each unit and, second, completely overwhelmed the program with their numbers. Directed to return to their units, the men responded by stripping the engines and airplanes of parts as souvenirs of the experience. Unsurprisingly, on 29 December, Army inspectors closed down the program. Opened again in January 1918, the school still proved unsatisfactory. Kelly officials then revised the curriculum, provided increased quantities of training equipment and reference materials, put the instructors through an extensive training course, and reopened the program once again on 18 March. The revised program was successful, and by 30 June 1918, it had graduated 419 airplane and 300 motor mechanics, as well as 195 motor transport specialists. These men ultimately were rated as some of the best technical personnel sent to the flying squadrons in the United States and in France. Subsequently, the Air Service expanded the program to a capacity of 1,000 students. Renamed the Air Service Mechanics School, it became the foundation for the technical training system operated by today's Air Force.[22]

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It is important to note that the men who went through these programs received general rather than system-specific training. In the case of engine mechanics, for example, they trained to work on *an* aero engine, not necessarily *the* aero engine that they would find when they reached the flight line. This was less true for mechanics assigned to flying fields in the United States, who usually received instruction on the ubiquitous Curtiss and Hall-Scott engines, especially after these became available in large numbers in early 1918. But many mechanics who had never touched anything but a Curtiss OX-5 suddenly found themselves confronting the mysteries of the geared Hispano-Suiza V-eight, the water-cooled radial Salmson, or the air-cooled Gnome and Le Rhône rotaries, in which the entire engine spun around its own crankshaft. These men still had to learn on the job, adapting their general knowledge to the peculiarities of whatever equipment their unit operated. In the last few months of the war, however, the Air Service addressed this deficiency by establishing specialized schools at various factories where engines were being built, including the Liberty Motor School in Detroit, Michigan; the Hispano-Suiza School at New Brunswick, New Jersey; and the Le Rhône Engine Course at Swissvale, Pennsylvania. System-specific instruction also took place in the Ignition Course at the Splitdorf Magneto Plant at Newark, New Jersey; the Instrument Course taught at

Langley Field, Virginia; and the Handley-Page School at the Standard Aircraft Corporation in Elizabeth City, New Jersey.[23]

In summary, by June 1918, the various approaches to maintenance and specialist training had succeeded in meeting the Army's most serious requirements in the United States and in France, enabling the Air Service to concentrate the body of its formal technical training programs at the Air Service Mechanics School at Kelly Field and the Dunwoody Industrial Institute. These programs functioned until the end of the war. Altogether, the different programs graduated 14,176 enlisted mechanics and technical persons by 11 November 1918.[24]

Now, where does the Royal Flying Corps come into all this? The Air Service made an early effort to establish its own maintenance training program in France; however, this approach quickly fell apart because of a lack of facilities, training equipment, and instructors. Thus, what training initially took place in Europe was on-the-job at the various flying fields and repair centers, and the Air Service turned to France and England to fill the mechanics training gap. The French Government proved much less helpful in this regard than in other areas. At the request of the French, in 1917, the Air Service, AEF ordered some 475 enlisted persons to French flying fields for instruction, while another 200 aero mechanics were sent to work in French aircraft factories where they received practical experience, if not formal training. These men served in the factories until Foulois requested their return in January 1918. But this was just a drop in the bucket compared to the number required—and the number trained with British assistance.[25]

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Help from Great Britain began in the United States when the Air Service took advantage of a training program already in existence. In July 1917, Colonel Cuthbert G. Hoare, commander of the Royal Flying Corps in Canada, proposed a reciprocal training program in which the Royal Flying Corps would train ten American squadrons in Canada in exchange for the use of three flying fields in the United States for winter training when weather closed many of the fields in Canada. The Air Service accepted the offer and built three fields at Camp Taliaferro near Fort Worth, Texas. Subsequently, Hoare offered to train an additional eight squadrons in exchange for extended use of these fields. Eight of the first ten squadrons trained under this program saw operational service in France; however, the process was hardly as straightforward as it seemed on the surface. Ultimately, the Canadian program trained some 4,800 American pilots, ground officers, and enlisted persons. It was a successful program but answered only a part of the need for trained mechanics.[26]

The concept of swapping training in exchange for warm bodies lay at the bottom of the most extensive training program established overseas during the war. Major Raynal C. Bolling had discussed training American mechanics with British authorities while the Bolling Commission was in England in June 1917, and in September, shortly after the first American air units reached France, several detachments in transit to France were diverted to England for instruction on British aircraft. These included the 34th Aero Squadron and 50-man detachments from seven other squadrons. These were joined in October by five additional flying squadrons and several construction units. Subsequently, negotiations between Pershing and

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Shipping problems handicapped the program from the beginning, however, and only 3,931 mechanics had reached England by 1 March 1918, the date by which all 15,000 were supposed to be on hand. Then, the German spring offensive forced Allied and American leaders to revise the shipping schedules in favor of ground troops, further delaying the arrival of trainees.[28] Shortages of shipping also interrupted the transport of construction personnel. As a result, the planned total of 15,000 men in training was not reached until August. Despite such problems, however, the British mechanics training program made an absolutely vital contribution to the development of the Air Service, AEF capability in France. As of 30 May, the Air Service had 73 flying squadrons, 18 repair squadrons, and 3 supply squadrons, mostly at British flying training fields. Almost all the men in the flying squadrons had some experience with Curtiss JN–4 *Jennies* and their OX-5 engines at American training fields. In England, they gained valuable knowledge on a wide variety of combat engines and airframes similar to those they would service in France.[29]

An officer who visited 15 training centers in England observed American mechanics doing "every class of skilled work required in connection with an aerodrome."[30] Inspectors who reviewed the program concluded that the Americans were more technical-minded than their British counterparts and had greater enthusiasm and higher morale—hardly surprising given that Britain was in its fourth year of seemingly unending bloodshed. Early shortages of training equipment, facilities, and experienced instructors took time to solve but were overcome. One problem proved impossible to resolve. Americans disliked English food. Most, one could say with some accuracy, would walk a mile for American canned *monkey meat* rather than indulge in English cuisine. And when it came to tea, the word *despised* suggests itself. Then, as now, *kippers* were hardly an American breakfast staple, and the US Army ran on coffee. Of greater significance, however, both British and American officials had a tendency to lose sight of the fact that training was the primary goal of the program. Too many wanted to treat the men as permanent replacements for British mechanics. Additionally, the dispersal of units across England made the program difficult to manage and forced the Air Service to establish an organization to track progress. Adoption of a reasonably standardized 3-month training scheme aided in this effort, as well. In June 1918, the Air Service also developed a standard squadron organization for the units in England, which through the addition or subtraction of 10 percent of its people could be modified into any type of flying

squadron required. Still, it might have been more efficient and less disruptive to manage the program by individuals rather than squadrons. Requests could have gone to England by specialty. Officials in London then would have filled those requests by selecting the best trained personnel from the locations where they could best be spared. These then would be sent to St Maixent in France where the aero squadrons were organized and equipped.[31]

By May 1918, Air Service officials faced a serious shortage of mechanics in France and sought to draw on those in England. British air leaders, however, had become dependent on American manpower and opposed releasing American units until replacements had arrived in accordance with the 5 December 1917 agreement. "I am thoroughly convinced that if tomorrow the majority of American squadrons were to be removed from England," 1st Lieutenant T. P. Walker of the Air Service reported, "the Royal Air Force would be severely crippled, and at certain stations, their training would come to a complete standstill."[32] To resolve the problem, General Patrick, new chief of the Air Service, AEF,[33] met with the British air officials in London "and placed our situation clearly before them." Bowing to American needs, the British agreed to release 3,500 mechanics who, Patrick agreed, would be replaced as quickly as replacements from the States became available.[34]

In June 1918, the first five squadrons—the 49th, 50th, 93d, 135th, and 213th Aero Squadrons—left England for France. As of 1 July, 72 squadrons were judged trained, and over the next few months, many of these rejoined the Air Service, AEF. All in all, the program provided a huge boost in trained maintenance personnel for the Air Service in France, as well as essential manpower for the Royal Flying Corps. The English program ultimately trained 22,059 men, of which 11,170 were sent to France. At least 18 of the 45 flying squadrons that fought with the Air Service on the Western Front received a major portion of their training in England. Other squadrons manned assembly plants, repair depots, flying fields, and airparks. Of those remaining in England, several were diverted to man the Handley-Page development program described below. Still others were in the personnel pipeline flowing to the Front when the armistice took effect.[35]

A large number of mechanics remained stuck in England, however, tied up by a program that, had the war lasted into 1919, might have led to an Air Service strategic bombing capability. The Handley-Page program grew out of the American desire to develop its own long-range bomber force. On 26 January 1918, Foulois signed an agreement with the British that provided for the manufacture in the United States of enough twin-engine Handley-Page bombers—powered by Liberty engines and equipped with all weapons, instruments, and accessories—to equip 30 American squadrons. These would be shipped to England in prefabricated pieces and assembled at production plants built especially for that purpose. The program also required shipping American personnel to England to construct the facilities required for the program, as well as providing enough mechanics to be trained to maintain the big airplanes. Final training for the squadrons would take place at several airfields in England.[36]

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The same kind of design and fabrication problems that delayed production of the De Havilland DH–4 and other aircraft afflicted the Handley-Page program. The big bomber was comprised of more than 100,000 parts, and construction was parceled out to several companies. But American industry proved incapable of making such a system function, and production quickly fell months behind schedule.

Work on the project began immediately. Assembly plants were established in two cotton mills near Oldham, and five airfields were identified as training sites. The Air Service shipped some 3,000 carpenters, bricklayers, and laborers to England to prepare these facilities. Instruction for the flying squadrons began at sites in the United States and continued in England using ten Handley-Page bombers borrowed from the British, powered by Liberty engines loaned by the US Navy. Unfortunately, as already noted, the project came to naught. First, the same kind of design and fabrication problems that delayed production of the De Havilland DH–4 and other aircraft afflicted the Handley-Page program. The big bomber was comprised of more than 100,000 parts, and construction was parceled out to several companies. But American industry proved incapable of making such a system function, and production quickly fell months behind schedule. By November 1918, only about 95 percent of the parts for 100 aircraft and less than 50 engines had reached England. Second, less than 60 percent of the production and assembly personnel reached England. Finally, bad weather, conflict with British trade unions, and frequent strikes delayed construction of the assembly facilities.[37] The one part of the program that worked well, unfortunately, was the shipping of several thousand potential mechanics to England for training. There they remained, waiting for aircraft that never arrived. Colonel Henry H. Arnold, later commander of the US Army Air Forces during World War II, concluded, "The only result [of the Handley-Page program] was that the American air outfits in France were deprived of their needed services."[38]

Despite all the training programs in the United States, England, and France, the Air Service never completely got a handle on maintenance personnel. The problem lay in two spheres, the malassignment of trained mechanics and the need to use them to accomplish additional military roles. Colonel Walter C. Kilner, chief of the Training Section for the Air Service, emphasized the deficiencies in trade testing, which was, all too often, done by Army officers with little knowledge of what they were doing. Trade testing, he asserted, should be done by experts in those trades, and he singled out the squadrons formed at Kelly early in the war as examples.

> Wood workers were rated as machinists, farmers as mechanics, and good machinists were given fatigue duties. Clerks were made mechanics, and good mechanics were made clerks, and then the entire squadron would be turned over to a supposedly technical officer for further training and assignment to duty. Under such conditions, it is not strange that mechanical work progressed slowly and that much of it was not properly done.[39]

Captain Charles W. Babcock, chief aeronautical engineer at the Third Aviation Instruction Center at Issoudun, reported that an improper distribution of mechanics plagued his maintenance efforts until the end of the war, and expert mechanics often were unavailable for duty because they were doing kitchen police, guard duty, or other labor.[40] The problem extended to specialists of all types. In August 1918, newly assigned 2d Lieutenant R. H. Wessman, armament officer of the 50th Aero Squadron, found his 13 armorers away from their duty stations "doing all kinds of fatigue work." Then, when he finally mustered his troops, he discovered that only three had any training for their duties.[41] Other units, like the 90th Aero Squadron, fared much better: "Specialized training was necessary," the unit history later stated about its enlisted

men, "but nearly all were by trade expert mechanics, who had volunteered for the work to which they were assigned and who were enthusiastic over the prospect of doing their *bit* along the lines for which they were peculiarly fitted."[42]

In July 1918, the Air Service formalized the process for assigning mechanics to the flying squadrons and forming squadrons in France. While most of the earlier squadrons had arrived more or less intact, deficiencies in their organization, the process of sending thousands of airmen to Europe for training, and the need for all pilots to receive flying training after they reached Europe had fragmented the squadron *mobilization* process. On 16 July, Patrick directed that all ground officers and enlisted men arriving in France, especially from the schools in England, would go to the Air Service Replacement Concentration Barracks at St Maixent. At St Maixent, the Air Service established a barracks, storage building, and trade center convenient by railroad to the main AEF base ports. There the new arrivals were trade-tested, given additional instruction, issued the correct personal equipment from the stocks maintained there, and reorganized into units as required. Once prepared, the units were sent temporarily to Orly, Romorantin, or one of the flying training centers. At these locations, squadron personnel augmented the permanent workforce, gaining in the process additional familiarity with their duties. From there, most units moved to the 1st Air Depot at Colombey-les-Belles where they met their new commanding officer, received contingents of Ordnance and Medical Department personnel, and secured all required squadron equipment and transportation. Airplane and motor spares were divided into squadron lots, park lots, and reserve lots, and shipped to the 1st Air Depot where they were issued to the squadrons and airparks as appropriate. A second reserve lot was sent to the Air Service, AEF spares depot. Pilots came from Issoudun and aircraft from the depots, acceptance field, or production center. The fully equipped squadrons were then directed to their front-line destination as complete units. As of 10 August 1918, the Coordination Section at Air Service Headquarters managed all aspects of this process. Section personnel knew at all times where each element was that made up a particular squadron, enabling them to anticipate requirements at each stage of the mobilization process, monitor developments, and massage any problems. The Air Service now had the ability to send squadrons to the Front according to a preplanned schedule rather than haphazardly as before.[43]

In summary, starting from almost nothing in April 1917, the United States had developed a modern, by contemporary standards, air force capable of providing minimum support to the field army operating on the Western Front. Within the United States, as has been discussed, the Air Service operated a training air force that provided itself with instructor pilots and the AEF in France pilots with basic flying skills. One part of the original program was never completed: the failure of American industry to produce suitable aircraft prevented establishing a complete training program at home and shifted the main burden of advanced flying training to France. The buildup of the Air Service in Europe had begun slowly but accelerated dramatically during the last 4 months of the war. The final numbers cannot be reconciled totally with confidence, but as of the last day of the war, the Air Service in France had received

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6,364 aircraft: 19 from Italy, 258 from England, 4,874 from France, and 1,213 from the United States.[44] Some 2,698 service aircraft had been sent to the Zone of Advance, while 714 service aircraft remained at the main depots and acceptance parks. Of those sent to the Zone of Advance, the operational flying squadrons had received 2,495 aircraft, while 203 remained in the advance air depots. Attrition had been high, and 1,627 service aircraft had been lost through accident or combat.[45]

At the armistice, the 45 squadrons of the Air Service, AEF at the Front were capable of providing reasonable reconnaissance and bombing support for the ground troops and aerial defense for itself. On the other hand, the size and strength of the AEF at that time actually justified a much larger air force, more than 100 squadrons. Further, the 45 squadrons at the Front were terribly under strength, fielding only 457 operational aircraft out of an authorization for more than 700.[46] In part, this was a result of the heavy losses during the Meuse Argonne fighting. In part, it resulted from difficulties with the type of equipment available like, for example, the complex and delicate, Hispano-Suiza-geared 220 hp engine that powered the Spad XIII. In part, it reflected a shortage of replacement aircraft, spares, and parts from the hardpressed French. But in part, it also was a result of the weaknesses in the maintenance training program that had taken so long to develop. World War I, in short, presented the US Air Service and its successor organizations with mixed results. Thanks to the assistance from the European allies, especially the Royal Flying Corps, it had come an incredibly long distance in an extremely short time. Yet, at the armistice, many weaknesses remained, and much more needed to be accomplished. Perhaps, it is most accurate to say in summary that a foundation for the future had been established, but little more.

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Notes

1. Quoted in Edward M. Coffman, *The War to End All Wars: The American Military Experience in World War I*, The University of Wisconsin Press, 1986, 11. Coffman remains, perhaps, the best single-volume study of the US experience during World War I.
2. On amalgamation, see Coffman, 9-10.
3. Quoted in John J. Pershing, *My Experiences in the World War*, 2 vols, New York, NY: Frederick A. Stokes Company, 1931, I, 38
4. The standard biographies of Pershing are Donald Smythe, *Guerrilla Warrior: The Early Life of John J. Pershing,* New York, NY: Charles Scribner's Sons, 1973, and Donald Smythe, P*ershing: General of the Armies,* Bloomington, ID: Indiana University Press, 1986.
5. For clarity, the term Air Service in this article refers to the military aviation establishment in the continental United States, and the term Air Service, AEF refers to that in Europe. The distinction is indicative of the division in US military aviation at the time. Military aviation in the United States began under the Aeronautical Division of the Signal Corps and remained under that branch of the service until 1918, although the name of the office changed several times. On 20 May 1918, aviation was separated from the Signal Corps and embodied in two organizations, the Director of Military Aeronautics and the Aircraft Production Board. These two, known already as the Air Service, finally were combined into a single organization on 27 Aug 1918. In contrast, Pershing separated aviation from the Signal Corps in the AEF in July 1917. The establishment in France, thus, became the Air Service, AEF and continued under that name throughout the war.

6. Again, for clarity, the Royal Flying Corps became the Royal Air Force on 1 Apr 1918, but this article will use RFC throughout. RAF will be used to refer to the service after the war.
7. John H. Morrow, Jr, *The Great War in the Air: Military Aviation from 1909 to 1921*, Washington, DC: Smithsonian Institution Press, 1993, 338. See also Lee Kennett, *The First Air War*, 1914-1918, New York, NY: The Free Press, 1991. On the US Air Service during World War I, see Arthur Sweetser, *The American Air Service: A Record Its Problems, Its Difficulties, Its Failings, and Its Achievements,* New York, NY: D. Appleton, 1919; Lt Lucien H. Thayer; *The Official History of the US Air Service, AEF (1917-1918)*, ed by Donald J. McGee and Roger J. Bender, San Jose, CA: R. James Bender Publishing, 1983; James J. Cooke, *The US Air Service in the Great War,* Westport, CN: Praeger, 1996.
8. Rebecca Hancock Grant, *Training to Fly: Military Flight Training, 1907-1945*, Washington, DC: Air Force History and Museum Program, 1999, 101-99, describes the development of Air Service flight training programs during World War I.
9. Maj Raynal C. Bolling, former counsel for the US Steel Corporation, led a team of military and industrial experts to Europe in June 1917 to determine the best equipment and materiel to be produced in the United States.
10. Morrow, 268-71, 321, 340-43. For extensive examination of US manufacturing failures, especially in aviation, see, Benedict Crowell, *America's Munitions*, 1917-1918, Washington, DC: Government Printing Office, 1919, and I. B. Holley, Jr, *Ideas and Weapons: Exploitation of the Aerial Weapon by the United States; A Study in the Relationship of Technological Advance, Military Doctrine, and the Development of Weapons*, New Imprint, Washington, DC: Office of Air Force History, 1983.
11. James J. Sloan, Jr, *Wings of Honor: American Airmen in World War I*, Atglen, PA: Schiffer Military/Aviation History, 1994, 104-107.
12. Morrow, 336, 337. Mitchell's activities during the St Mihiel offensive are detailed in James J. Cooke, *Billy Mitchell*, Boulder, CO: Lynne Rienner Publishers, 2002, 84-94.
13. Tami Davis Biddle, *Rhetoric and Reality in Air Warfare: The Evolution of British and American Ideas About Strategic Bombing, 1914-1945*, Princeton, NJ: Princeton University Press, 2002, 53.
14. Brig Gen Benjamin D. Foulois, one of the US Army's earliest aviators, replaced Brig Gen William Kenly as chief of the Air Service, AEF on 27 Nov 1917.
15. Biddle, 53-56.
16. Alexandre Ribot was the French premier. His cable called for the United States to produce 4,500 planes, 5,000 pilots, and 50,000 mechanics and became the basis for early Air Service planning.
17. Hiram Bingham, *An Explorer in the Air Service*, New Haven, CN: Yale University Press, 1920, 59-60; Sweetser, 140-41.
18. Royal D. Frey, "Evolution of Maintenance Engineering, 1907-1920," Historical Study No 327, Historical Division, Air Materiel Command, Jul 60, 83.
19. Frey, 86-87.
20. Sweetser, 143-44; Lt F. J. Pendergrast, "History of the Air Depot at Fairfield, Ohio, 1917-1943," 6-7, Microfilm Reel A2107, Frames 186-626, Air Force Historical Research Agency (AFHRA), Maxwell AFB, AL.
21. Frey, 88-89.
22. Henry H. Arnold, "Aviation Section, Signal Corps, and Division of Military Aeronautics, April 1917-October 1918," nd, 10, 168.65011-4, Ernest L. Jones Collection, AFHRA; Sweetser, 144; Frey, 85-86.
23. Frey, 106.
24. Frey, 89-90.
25. Maj Gen Mason M. Patrick, "Final Report of the Chief of the Air Service, AEF," in Maurer Maurer, ed, *The US Air Service in World War I*, 4 vols, Washington, DC: Office of Air Force History, 1978, I, 55, 58-59; Memo, Maj Birdseye B. Lewis, Materiel Division, Air Service,

AEF, to ACA, 25 Sep 17, atch to Supply Section Questionnaire, 4 Jan 19, Box 4, the papers of Col Halsey Dunwoody, AFHRA.

26. Arnold, "Aviation Section, Signal Corps, and Division of Military Aeronautics," 5-6; Frey, 87; S. F. Wise, *Canadian Airmen and the First World War*, Vol 1, The Official History of the Royal Canadian Air Force, Toronto, CDN: The University of Toronto Press, 1980, 91-97.
27. Rpt No 6, Maj Raynal C. Bolling to Chief Signal Officer, subj: Conference Between American Representatives and Subcommittees of the Air Board, 29 Jun 1917, Box 4, Dunwoody Papers, AFHRA; Patrick, "Final Report of the Chief of the Air Service, AEF," 59; Thayer, 249-50. Pershing's cable announcing the program may be found in Lt Col G. M. Murphy, General Staff, AEF, "Recapitulation of United States Air Service Work in Great Britain & Ireland," nd, Series A, Vol 16, Roll #4, "Col Gorrell's History of the US Army Air Service," Microcopy, T-619, The National Archives, Washington, DC.
28. This operation, code named Kaiserschlacht, erupted on 21 Mar 1918 and, for a time, threatened to rupture the entire Allied front. The emergency led Pershing to agree to transport riflemen by ship from the United States in large numbers rather than complete, balanced infantry divisions. Less room remained for personnel from other organizations like the Air Service, AEF, as well.
29. Thayer, 251.
30. Memo, 1st Lt T. Walker, to chief of Personnel, Air Service, AEF, subj: American Squadron Training in England, nd, Series A, Vol 15, Roll #4, Gorrell.
31. Walker; Frey, 137-44, 168.
32. Walker.
33. Maj Gen Mason M. Patrick, an engineer and nonflyer, replaced Foulois as Chief of the Air Service, AEF on 29 May 1918. He served in that capacity through the armistice.
34. Maj Gen Mason M. Patrick, *The United States in the Air*, Garden City, New York, NY: Doubleday, Doran and Company, 1928, 19-20.
35. Thayer, 252-53; Frey, 146.
36. Crowell, 261-62; Thayer, 37.
37. Rpt, Capt N. W. Owens, Adj, Night Bombardment Section, to Aviation Officer, BS No 2, SOS, AEF, subj: Handley-Page Operations in England, 16 Jan 1919, Series A, Vol 15, Roll #4, Gorrell; Thayer, 253-54.
38. Henry H. Arnold, *Global Mission*, New York, NY: Harper & Brothers, 1949, 71.
39. Col Walter C. Kilner, Chief, Training Section, in Maurer, *US Air Service*, IV, 328.
40. Capt Charles W. Babcock, Chief, Aeronautical Engineer, Third Aviation Instruction Center, in Maurer, *US Air Service*, IV, 244.
41. 2d Lt R. H. Wessman, armor officer, 50th Aero Squadron, in Maurer, *US Air Service*, IV, 234.
42. Leland M. Carver, Gustav A. Lindstrom, and A. T. Foster, *The Ninetieth Aero Squadron, American Expeditionary Forces*, Hinsdale, IL: E. Harold Griest, 1920, 10.
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Air Vice-Marshal Peter J. Dye, RAF

Logistics Lessons from the Past—Deployed Operations

Wot makes the soldier's 'eart to penk, wot makes 'im to perspire? It isn't standin' up to charge nor lyin' down to fire; But it's everlastin' waitin' on a everlastin' road; For he commissariat camel an' is commissariat load.

Northern India Transport Train—Barracks-Room Ballads
—Rudyard Kipling

Logistics is not so much a science as an art and yet, under the pressure of tighter budgets and downsizing, there is great temptation to adopt the view that sophisticated resource modeling and realistic simulation (including wargaming), together with careful staff work, are sufficient in themselves to provide for effective support of deployed operations. But anyone who has had to maintain aircraft or other complex weapons systems, whether at home or overseas, will know how the unexpected can rapidly degrade effectiveness, notwithstanding the resources available, or the depth and detail of the advance planning.

I am not suggesting we cannot continue to use the techniques mentioned above (and others) to control costs and improve our logistics support. However, much of our recent experience relates to a scenario that increasingly appears to have been driven by an exceptional period in world affairs. Whether we like it or not, our current methods of doing business largely reflect the lessons learned in the Cold War and are tailored to supporting the main base concept. Of course, we cannot simply abandon tried and tested procedures, but we are entering a period of radical change and a concept of operations that owes more to the Royal Air Force's (RAF) experience up to 1945 than the subsequent 50 years of *peace*. Recent studies have addressed the RAF's conceptual framework for developing its capabilities to deal with new realities. Nevertheless, it is very much new territory, with few examples and little practical experience to draw upon. That being so, I would suggest there

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is considerable merit in looking at how the RAF supported deployed operations in the first half of this century, as part of the ongoing process to develop our post-Cold War logistics strategy.

To those who suspect my thesis implies things were done better in the past—that there was a sort of logistics golden age—note the deployment in 1916 of the No. 29 Squadron to join the Expeditionary Force. No. 29 Squadron had been formed at Gosport from the No. 23 Squadron in November 1915. Towards the end of January 1916, 20 DH-2 Scouts were allotted to the new squadron. It was decided (somewhat rashly as events proved) to deploy the ground crew and support personnel, together with the squadron transport, ahead of the aircraft move. The former proceeded overseas on 14 March. Ten days later, the aircraft set off for Dover, but mechanical problems (exacerbated by inexperience with the new aircraft, the fact that the squadron had been largely without ground crew for nearly 2 weeks, whilst most of those remaining had contacted measles), poor weather, and accidents en route meant that by the second week of April only 12 machines had actually reached France. The overall attrition was even worse than one might suppose, since the original allocation of 20 aircraft had been supplemented by further deliveries direct from the manufacturer (but none with compasses fitted, which raised some concerns amongst those pilots, who had managed to reach Dover, as to the wisdom of a Channel crossing). Headquarters Royal Flying Corps (HQ RFC) subsequently calculated that, "the total number of machines consumed, in order to deliver at St. Omer 12 serviceable, was 27."[1] The majority of these were scattered around Southern England, some written-off, whilst others ditched in the Channel or crashed on landing in France. The pilots involved fared little better, suffering their fair share of injuries, as well as measles, such that the last arrived in France over 2 weeks later. All in all, it was not one of the RFC's finest hours.

Whilst this catalogue of disasters may be entertaining at this distance, I doubt there are any fundamental lessons to be learnt. However, there are aspects of RAF deployed operations in the Second World War that are actually quite instructive.[2] One example is the logistic support for the RAF elements involved in Operation TORCH, the North African landings that took place in December 1942. Some 450 aircraft were involved in the Eastern operation, centred on Algiers, tasked with providing air cover for the shipping and ground forces, and, once ashore, to protect against air attack and to support the subsequent land advance. Immense difficulties were encountered as this was the first large-scale amphibious landing to be undertaken by the Allies. It was also the first real test of Anglo-American cooperation, the conduct of joint operations and, most importantly, of joint planning. As far as the air element was concerned, it was agreed that the Army would provide fuel and weapons, whilst the RAF would furnish all support vehicles, ground equipment, and technical stores. The relevant equipment was packed at maintenance units in the UK to schedules prepared by the Air Ministry, but the sponsoring branches had no visibility of what was actually provided. It was subsequently reported by the

units making up the packs that there were 72 percent inabilities. All *pack-ups* were allocated, in the interests of security, field unit serial numbers. The code for these numbers was given a very limited distribution and not included in the administrative instructions. All stores were then loaded at UK ports for travel by convoy directly to join the Eastern Task Force at Gibraltar.

The actual landings met little opposition and the advance RAF ground parties were able to reach their designated airfields and receive the first Allied aircraft by 1030 on the morning of D Day. Thereafter matters got more difficult. Enemy air attacks commenced in earnest, fuel was in extremely short supply, and essential equipment either did not arrive at the beachhead or was lost on landing (this problem was exacerbated by the limited attention that had been paid to the loading of the ships in the UK such that in some cases it took 2 days to unload priority equipment). It would be wrong to suggest the planners had not anticipated the difficulties likely to be faced in landing large quantities The variety of aircraft and engine types vastly increased the difficulty of supply and repair at the school. More significantly, however, the RAF embarkation staff of 26 personnel of all ranks was quite incapable of sorting the mountains of equipment being discharged. The result was not only were the docks swamped with piles of stores which in fact would not be needed for many weeks, but there was also no means of distinguishing between cases. A great deal of unnecessary equipment found its way to the forward areas in place of items that were urgently required. To make matters worse, although the consumption of ordnance was far less than had been anticipated, the early consignments of bombs arrived with the wrong components or without components at all; this included fusing links. By the end of January the process of marrying up bombs with tails had still not been completed satisfactorily (without wishing to exaggerate, there are echoes of our own experience during Operation GRANBY). There was also the usual share of unexpected, and hence unplanned, maintenance problems. For example, the soft state of the airfields following heavy rain resulted in a large number of aircraft ground looping and breaking their propellers, therefore stocks were rapidly exhausted.

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Logistic problems did not end here. The numbers of RAF movements staff were totally inadequate to the task and thus had to rely upon Army movements personnel. But without the key to unit serial numbers, the latter could only surmise for whom the equipment was intended. This generally ended in it being sent to the wrong unit, who, knowing only its own serial number, could not dispose of the equipment to its proper destination. As a result, much of the equipment off-loaded from the first convoy into Algiers did not reach the correct units until many weeks had elapsed. Finally, when the pack-ups were opened it was often found the items required were either missing or present only in reduced quantities.

Those involved in the handling of stores at Al Jubayl during Operation GRANBY nearly 50 years later many have noticed some similarities between their experiences and the problems encountered in Operation TORCH. In neither event was there

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This is not to say the logistic planning had failed to make provision for the sustained support of aircraft operations, but it had been envisaged that the majority of squadrons once ashore would be rapidly joined by their assigned maintenance personnel, as well as air stores parks (with sufficient equipment to support 30 days' maintenance) and repair and salvage units.

effective enemy action to interrupt the supply chain and yet immense difficulties were encountered simply as a result of the scale and pace of the buildup, the sheer volume of stores and the almost impossible task of locating specific equipment amongst the countless crates and International Standards Organisation (ISO) containers on the dockside. One is forced to conclude that moving thousands of tons of stores across a continent has always been the simplest (but not necessarily the easiest) part of any logistic operation. My personal experience during Operation GRANBY would suggest, however, that even this statement has to be qualified. I recall on one occasion a serviceable aeroengine, urgently required at Muharraq, returning from Lyneham on the same lorry that had rushed it down there—much to the distress of the driver. More importantly, the original inbound unserviceable engine was at that very moment winging its way back to the Gulf in the back of a Hercules! To be blunt, delivering the required item, to the right hands, at the right place and at the right time, remains the overriding challenge for any logistic organisation. It is also true that forging the last link in the support chain can be as difficult as assembling the remainder. It is a task made all the more challenging in a joint multinational environment, subject to the vagaries of host-nation support and the inevitability of unplanned (and hence inadequately provisioned) unserviceabilities. The way ahead must surely lie in both improving asset tracking and also providing greater visibility of the supply chain to all parties, including the consumer as well as the supplier.

One of the unique aspects of the RAF's logistic planning for Operation TORCH was the creation and employment of servicing commandos. These units comprised up to 150 RAF tradesmen, with intensive combat training, who were to be landed during the assault phase and would be capable of defending themselves (and their aircraft), whilst also undertaking the daily servicing, refueling and rearming of aircraft operating from advance landing grounds and captured airfields until such time as the main squadron servicing parties arrived. In theory, the servicing commandos—although entirely comprised of Trade Group 1 (technical) personnel—could only provide rudimentary support as their tools and equipment would be necessarily limited. However, the two servicing commandos employed during Operation TORCH had to undertake the maintenance of many more squadrons, of several aircraft types, and for a considerably longer period than originally intended owing to the difficulties outlined above as well as problems in assembling and moving the appropriate technical personnel forward. In fact, instead of being relieved after a few days, they were employed continuously for 5 weeks without rest.[3] Notwithstanding the servicing commandos' efforts, the lack of maintenance facilities and skilled personnel soon began to make itself felt in the form of reduced aircraft serviceability. This is not to say the logistic planning had failed to make provision for the sustained support of aircraft operations, but it had been envisaged that the majority of squadrons once ashore would be rapidly joined by their assigned maintenance personnel, as well as air stores parks (with sufficient equipment to

support 30 days' maintenance) and repair and salvage units. Quite deliberately there had been no provision for major repair (beyond what the repair and salvage units could undertake) in the anticipation of a relatively brief campaign. In the event, the operational commanders decided to accelerate the aircraft deployment plan and this, coupled with the supply chain difficulties already outlined, meant squadrons were compelled to operate for some time without support equipment, adequate servicing and repair arrangements, or even transport and signals support. Typical of these difficulties was the plight of the two Beaufighter night fighter squadrons called forward 3 weeks early. On arrival they had to be maintained by members of the aircrew, co-opted ground personnel from a collocated Hudson squadron, and mechanics from a repair and salvage unit. To compound these problems, the Beaufighters' radar equipment had been removed for security reasons and sent by sea with the ground personnel. Therefore, an emergency supply of radar equipment had to be flown out direct from the UK before night fighter operations could commence. But, not surprisingly, the hastily assembled maintenance team found the radar extremely difficult to install without any specialist knowledge or the appropriate support equipment and tools.

Eventually, the second line maintenance units were able to come into action, but this did not immediately resolve every problem. The repair and salvage units found they faced an immense backlog of repairs because of the delays and were effectively immobilised whilst the stores parks discovered the storage space provided by the Army was but a fraction of their actual requirements. Eventually some additional space was found in local farm buildings. Strenuous efforts were made to recover this situation as the campaign developed by improving both the support arrangements as well as the mobility of the squadrons. Maintenance personnel in the forward area were reduced to a minimum to enable the squadrons to be placed on a mobile basis capable of movement at short notice utilising their own motor transport. The remaining maintenance personnel were withdrawn to the rear echelons. The forward stores parks were also reduced to *immediate issue* stocks only (and the personnel reduced accordingly), whilst the repair and salvage units were totally withdrawn, other than small mobile sections to work with the squadrons. In general, these new arrangements worked well and would provide the pattern for all subsequent campaigns.

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Amongst the many other lessons learnt from Operation TORCH was the need to schedule carefully the arrival of equipment and stores, whilst ensuring the necessary personnel and repair facilities were in place as early as possible to permit effective air operations. That said, it was also clear too large a forward support organisation would take a disproportionate share of the available shipping and assault craft, whilst also serving to hinder subsequent mobility. Exercises undertaken in the UK during 1943, in preparation for the Normandy landings, confirmed the overriding importance of reducing what might today be referred to as the *deployment footprint*. In fact, how best to organise the maintenance support for squadrons whilst enhancing

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After toying with a proposal to do away with all maintenance personnel and rely entirely upon station support (the centralised approach), it was agreed a semiautonomous organisation should be adopted, whereby the bulk of the repair responsibility, associated tradesmen and ground equipment would be transferred to the station maintenance party, leaving only sufficient squadron maintenance personnel to conduct daily servicing and minor inspection tasks.

their mobility, was a question which group and command staffs had been struggling with since 1940. Prior to the expansion of the RAF, fighter squadrons were largely self-sufficient, each flight having the capability to undertake in-depth repair, as well as the normal servicing functions. It was soon evident this system could not cope with the increased flying rate and greater technical complexity that accompanied the expansion programme. As a result, maintenance support was reorganised on a squadron basis; two flights being responsible for servicing tasks, whilst the third flight undertook major repair work and the deeper inspections. This system, which today we would probably describe as an *autonomous* maintenance organisation, remained in force for the first year of the war. However, during the Battle of Britain it was discovered that the mobility of squadrons was adversely affected and the frequent squadron moves resulted in the maintenance personnel being increasingly detached from their units, sometimes being spread over at least three different stations.

In an endeavor to improve the mobility of the squadrons and avoid the need to transport large ground parties and redundant bulky equipment from station to station, it was decided to reexamine the maintenance system. After toying with a proposal to do away with all maintenance personnel and rely entirely upon station support (the *centralised* approach), it was agreed a *semiautonomous* organisation should be adopted, whereby the bulk of the repair responsibility, associated tradesmen and ground equipment would be transferred to the station *maintenance party*, leaving only sufficient squadron maintenance personnel to conduct daily servicing and minor inspection tasks. The squadron engineer officer would remain in the squadron but the station maintenance party would provide echelons attached to each squadron, albeit under the command of the station engineer officer. These echelons could also provide a mobile unit to accompany the squadron for *bare-base* moves.

Over the next few years this organisation was further developed to become almost fully centralised; the supporting technical personnel were in effect entirely divorced from the flying squadrons. A three-tier structure was introduced comprising: (1) the *Advanced Landing Ground*, where quick turnaround servicing would be carried out by servicing commandos (as already described); (2) the *Airfield Area*, capable of supporting three squadrons where servicing was fully centralised under the station maintenance party; and (3) the *Base Area* that undertook maintenance beyond the station maintenance party's capability or capacity to complete in under 48 hours. The Airfield Area was in essence a mobile station, but to achieve this it was necessary to create additional support units, including repair and salvage units and forward stores parks. This system was extremely successful in providing effective support to the RAF's flying squadrons, both through the North African and Italian campaigns as well as during and after the Normandy landings. It should be noted that, notwithstanding the centralised maintenance organisation, particular efforts were made to sustain squadron identity by affiliating Airfield Area echelons to specific squadrons under a squadron technical officer. This also served to improve the welfare

and management of the technical personnel concerned. That said, such pragmatism was not allowed to detract from the overall policy of centralisation.

As a footnote, the sort of problems experienced by the No. 29 Squadron in 1916 were resolved by making temporary provision at the base airfields in Southern England for maintenance support, while the squadron servicing personnel established themselves in Normandy. In the event, the maintenance arrangements worked extremely well. The first servicing commandos landed on D+1 and received their initial aircraft on D+2 (on a temporary basis, for refueling and rearming). By the afternoon of D+3 some 3,500 RAF personnel and 815 vehicles had been landed. The permanent move of fighter squadrons to airfields in Normandy commenced on D+4, once the Airfield Areas were ready to receive them. Thereafter the pace of deployment accelerated such that, by the end of June, one wing was arriving every 5 days. Once again, the servicing commandos had proved invaluable, not only enabling damaged aircraft to return back to base, but also ensuring an extremely high availability rate. Nevertheless, once the bridgehead was established and the Airfield Areas in theatre, their importance rapidly declined and they were withdrawn at the end of July.

As in Operation TORCH, a number of environmental maintenance problems arose. Rather than wet airfields, the cause in this instance was dust. The soil on which the landing grounds were constructed contained a very high proportion of silica which lessened the life of engines, particularly those not fitted with air-cleaning devices (such as the Typhoon's Sabre). Unserviceabilities rapidly rose and it was only by pumping oil and water onto the airfield surface and minimising warm-up times that the problem could be contained (but not before 66 engines had been damaged beyond repair). There are echoes again here of the RAF's experience in Operation GRANBY. I would only add that maintaining sophisticated aircraft and weapons systems outside of their normal operating environment is something that has to be practised. Careful planning, experience, and foresight are not a substitute for the real thing!

Following the Normandy breakout, the primary problem facing the maintenance organisation was the ever lengthening lines of supply. Transport aircraft were used to supplement the supply chain and, in particular, to deliver aviation fuel to help support the momentum of the advance. This was successful, and at no stage were operational units ever prevented from carrying out sorties for lack of supplies. In order to avoid bottlenecks and minimise forward storage requirements, the provisioning system was based upon a *call-forward* principle, rather than the base organisation sending supplies into the theatre at will. This has clear parallels to today's concept of *just-in-time* supply and express chain management.

Turning to the lessons we might draw today, I would first observe that the RAF's organisational structure to support deployed and mobile aircraft operations in the Second World War took some 4 years to perfect. The result was a lean, efficient system that: sustained high availability; enhanced squadron mobility, flexibility

Turning to the lessons we might draw today, I would first observe that the RAF's organisational structure to support deployed and mobile aircraft operations in the Second World War took some four years to perfect. The result was a lean, efficient system that: sustained high availability; enhanced squadron mobility, flexibility and economy in manpower and equipment; and enabled squadron commanders and airmen to concentrate on their operational responsibilities.

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and economy in manpower and equipment; and enabled squadron commanders and airmen to concentrate on their operational responsibilities.[4] It may well be the servicing commando concept—given the remote possibility we will again be required to participate in an amphibious assault on a hostile shore—will remain simply an historical curiosity. Nevertheless, and notwithstanding the passage of time and subsequent technological development, the lessons of 1939-1945 provide much food for thought in deciding how best to develop logistics support. Do we really have the right maintenance organisation to cope with the post-Cold War era? To date, studies have focused largely on the mechanics of deployment support and the resourcing implications rather than the organisational aspects and how this might be developed to enhance mobility and reduce the forward support requirements, particularly the deployment footprint. I have always been an enthusiastic proponent of the semiautonomous maintenance organisation, believing the enhanced squadron *esprit de corps* brings very real benefits. But, this should not blind us to the very real issue of whether such a system is the best or indeed the only way to support deployed operations in the future. Is there not a very real danger that we are solving tomorrow's problems with today's solutions? At the very least the question should be debated.

Notes

1. AIR 1/127/15/40/152, Public Records Office, Kew, London, UK.
2. Much of the source material comes from the Air Historical Branch, *Official History on The Development of RAF Maintenance 1939-1945*, published in 1954.
3. Davies and Kellett, *A History of the RAF Servicing Commandos*, 1989.
4. Report on the Air and Administrative Organisation of the 2d Tactical Air Force, Air Ministry, 1947, 89. Pact with Germany and Italy on 27 September 1940, a pact that was aimed directly against the United States, further exacerbated US-Japanese relations.

Lieutenant Colonel Patrick H. Donovan, USAF

Oil Logistics in the Pacific War

Oil's Role in Japan's Decision for War

The shortage of oil was the key to Japan's military situation. It was the main problem for those preparing for war, at the same time, the reason why the nation was moving toward war.… Without oil, Japan's pretensions to empire were empty shadows.

—Louis Morton, *Command Decisions*[1]

Oil played a crucial, if not the key, role in the Japanese decision to go to war with the United States in 1941. Because of the deteriorating political situation with the United States, United Kingdom, and Netherlands East Indies, the future of Japan's oil reserve and supply was in danger. When diplomatic efforts failed to resolve the political impasse, Japan made plans to seize militarily what it could not achieve diplomatically. An inevitability of this military option was war with the United States. With this in mind, the Japanese planned to terminate any short-term American threat quickly and seize needed oil at the same time. Time, like the Japanese oil supply, was running out quickly.

Oil Available in the Netherlands East Indies

June 1941 was a pivotal month for the future of Japanese oil supplies. The Japanese had been in economic negotiations with the Netherlands East Indies (NEI) Government in Batavia since September 1940 and were seeking a special economic position in the Netherlands East Indies. Previous embargoes of aviation fuel, iron, and scrap steel by the United States in July and October 1940 (to counter the Japanese occupation of northern French Indochina) had sent the Japanese searching for alternative sources of raw materials. Also, the entrance of Japan into the Tripartite Pact with Germany and Italy on 27 September 1940, a pact that was aimed directly against the United States, further exacerbated US-Japanese relations. The Netherlands East Indies seemed to fit this bill, the Nazis (a putative partner of the

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The move into southern French Indochina was not without some internal debate in Japan. In the end, however, it was decided that the military occupation of the territory was too good an opportunity to pass up.

Japanese) had overrun the NEI's parent country, and its geographic location put the Japanese closer to the Netherlands East Indies than any of the latter's allies. Thus, the Netherlands East Indies was deemed to be more malleable to Japanese desires than the increasingly recalcitrant United States. Some of Japan's demands included participation in NEI natural resource development and freedom of access and enterprise in the Netherlands East Indies, as well as a steady supply of oil. However, Japanese aspirations were about to receive a serious setback.[2]

The NEI Government was willing to negotiate with the Japanese, but Batavia was not willing to yield special economic concessions to the Japanese (there were to be increases of nonpetroleum products). Although these increases were less than what was sought, they did fulfill Japanese needs. Japanese requests for larger exports of oil were passed on to the NEI oil companies, but these requests were deferred. Also, Japanese requests to conduct military and political activities in the Netherlands East Indies were also rejected. On 17 June 1941, economic talks were broken off between Japan and the Netherlands East Indies.[3]

Almost directly on the heels of the breakdown in talks between Batavia and Tokyo was an announcement from the United States on 20 June 1941 that, henceforth, no petroleum would be shipped from the US east coast, or gulf coast ports, outside the Western Hemisphere. There was a shortage of fuel for domestic use on the east coast of the United States in June 1941. To ship fuel out of areas with shortages to semibelligerent foreign governments was politically untenable for the US Government. Thus, from Japan's point of view, the commodity most desired by them was being choked off.[4]

Because of this reversal of fortunes, Japan felt it must make a move toward securing a source of oil in Southeast Asia:

> Consequently, at an Imperial conference on 2 July, Japan decided to adopt the "Outline of the Empire National Policy to Cope with the Changing Situation." By executing a daring plan calling for the occupation of southern French Indochina, Japan hoped to gain dominance over the military situation in the southern areas and to force the Netherlands East Indies to accede to her demands.[5]

Japan Needs a Secure Source of Oil

The move into southern French Indochina was not without some internal debate in Japan. In the end, however, it was decided that the military occupation of the territory was too good an opportunity to pass up. By occupying the southern half of French Indochina, the Japanese would consolidate their strategic position; it would stop the encroachment of the ABCD powers on her economic life line. Also, the occupation would be a blow to the Chungking government and help settle the China issue; it would also put pressure on the NEI Government to come to terms with Japanese demands.[6] The Japanese were not making this move as a step toward provoking the United States, Britain, or the Netherlands East Indies to war; Tokyo wished economic negotiations to continue. The move into southern Indochina was

a preemptive action that would help the Japanese if conflict with the ABCD powers became inevitable.[7] One wonders if the Japanese later realized that their actions eventually turned into a self-fulfilling prophecy.

The Japanese did not consider how the ABCD powers would react to Tokyo's move into southern Indochina.[8] Indeed, Tokyo felt that this move was possible because it believed the threat of US economic sanctions to the Japanese move to be less than 50 percent. The Japanese still moved forward, even though President Franklin D. Roosevelt had hinted to Kichisaburo Nomura, the Japanese Ambassador to the United States, that sanctions would occur if Tokyo moved troops into southern Indochina.[9] However, the Japanese felt that the United States would not follow through with such a move because it would provoke a war at a time when the United States was not ready to fight.[10]

There was some logic in the Japanese thought process. Since March 1941, the United States and Japan had been in dialogue to avoid such a war. However, as much as the United States wanted to avoid war, it would not do so at the sacrifice of basic principles of international conduct.[11] Therefore, reaction from the United States was swift. With the Japanese movement into southern French Indochina, the United States froze all Japanese assets on 25 July 1941.[12] The governments of Great Britain and the Netherlands East Indies soon followed with their own freezing actions.[13]

With this freezing action came a complete embargo of all oil products into Japan by these countries. It was not the intent of Roosevelt to bring about a complete embargo of oil to Japan.[14] He felt that such an action would cause the Japanese to invade the Netherlands East Indies and Malaya to seize the oilfields there. This would possibly suck the United States into an early conflict in the Pacific, a conflict the United States was not prepared for and which would be at the expense of devoting energy toward the European conflict.[15] Roosevelt's freeze order allowed the Japanese to apply for export licenses for oil; however, hard liners within Roosevelt's administration acted as if the freeze were total, so no licenses were ever approved.[16]

This situation put the Japanese into a quandary; they did not gain any oil by moving into southern Indochina. Now they had isolated themselves from 90 percent of their annual requirements. The Japanese did have a strategic reserve in place that they had been building up since the early 1930s. So some time was available to try and find a diplomatic way out of the impasse.[17]

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Oil in the Netherlands East Indies Cannot Be Secured without US Intervention

Throughout the summer and into the fall of 1941, Japanese negotiators and the United States were at loggerheads. The US-led embargo would not be suspended until the Japanese stopped their militaristic expansion; indeed, Japan would have to roll back some of its gains. Included in the US demands were calls for a retreat from all French Indochina and China. This demand was unacceptable to the Japanese.[18] Likewise,

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the minimum demands of the Japanese stated that the United States must accept the current status quo in east Asia with vague promises that the Japanese would withdraw from disputed areas once peace had been established in the Far East on a fair and just basis.[19]

Meanwhile, Japanese oil stocks were dwindling. If the Japanese could not get oil by negotiation, they would have to use force. The nearest available source was in the Netherlands East Indies. Would it be possible to seize the oil there without involving the British and the Americans? There were numerous reasons why Tokyo felt this was not the case.

As far back as 1909, the United States was identified as one of the principal enemies of Japan.

The Japanese had come into possession of British War Cabinet minutes that stated the British would fight alongside the Dutch if the Japanese invaded the Netherlands East Indies.[20] The Japanese were also aware that any conflict involving them and the British would draw the United States into conflict on the side of the British.[21] The director of the War Plans Division of the Navy Department, Admiral Richmond Kelly Turner, confided this policy to Nomura "that the United States would not tolerate, in view of its policy of aiding Britain and its interpretation of self-defense, a Japanese threat to the Malay barrier."[22] The United States was not limiting its interest to the British. In a note handed to Nomura from Roosevelt, the United States stated any further aggression by Japan against its neighbors and the United States would be forced "to take immediately any and all steps which it may deem necessary" to safeguard US interests.[23] Finally, the Japanese foreign office believed some type of military understanding had been reached among Washington, London, and Batavia. The Foreign Office produced two reports that supported its claims that a joint ABCD defense understanding existed and was being implemented.[24]

Even with this potential alliance arrayed against them, could the Japanese afford to dismiss the warnings as bluster? As appealing as the thought was, the B-17s based at Clark Field and the Cavite Naval Base in Manila Bay were too much of a strategic threat to the Japanese lines of communication. Any shipments of raw materials that the Japanese might acquire in the Netherlands East Indies or Malay Barrier could potentially be attacked by US forces stationed in the Philippines. Because of this, those US forces would have to be dealt with if the Japanese could not get the resources they needed diplomatically.[25]

All these factors played into the Japanese belief they eventually and inevitably would come into conflict with the United States. As far back as 1909, the United States was identified as one of the principal enemies of Japan.[26] Indeed, the Japanese realized fairly soon after the oil embargo was imposed that the Japanese and American positions were mutually exclusive. At the 6 September 1941 Japanese Imperial Conference, materials addressing such a question were distributed to the participants.

> *Is War with the United States Inevitable?*…it appears that the policy of the United States toward Japan is based upon the idea of preserving the status quo and aims, in order to dominate the world and defend democracy, to prevent our empire from rising and

> developing in Eastern Asia. Under these circumstances, it must be pointed out the policies of Japan and the United States are mutually inconsistent and that it is historically inevitable the conflict between the two countries, which is sometimes tense and moderate, should ultimately lead to war.
>
> If we should ever concede one point to the United States by giving up a part of our national policy for the sake of a temporary peace, the United States, its military position strengthened, is sure to demand tens and hundreds of concessions on our part, and ultimately, our Empire will have to lie prostrate at the feet of the United States.[27]

It should be noted that these were not the views of one individual alone but those of the government and the supreme command of the Japanese military. If Japan were to obtain the oil and other resources it needed, it would have to control the Netherlands East Indies and the Malay Barrier. Japan also would have to remove the US threat to this plan.

Pearl Harbor and the Southern Operation

Japanese naval strategy was built around the premise that when the United States and Japan went to war it would be a one-time decisive battle. The Japanese believed a large American fleet, as much as 40 percent larger than the Japanese fleet because of restrictions imposed by the Washington Naval Treaty, would drive across the Pacific to attack the Japanese. During this drive, the Japanese would initially send out submarines to whittle down the size of the US fleet. Closer in, the Japanese would throw land- and carrier-based aircraft into the battle. Once the reduced US fleet was far enough into the western Pacific, the Imperial Japanese Navy (IJN) would sortie out and engage in a classic ship of the line battle that the Japanese would inevitably win.[28]

Japanese naval strategy was built around the premise that when the United States and Japan went to war it would be a one-time decisive battle.

The problem with this strategy was that it was passive. Japan would have to devote the majority of its fleet to support amphibious landings if the Southern Operation of seizing the Netherlands East Indies and Malay Barrier were to succeed. The decisive battle plan left the initiative and time of the conflict up to the US Navy. This left Japanese forces even more at risk after the US Pacific Fleet's move to Pearl Harbor. If that fleet could be neutralized or destroyed at Pearl Harbor, it would deprive the US fleet of any initiative and allow the Japanese to run unhindered in the southern area.[29] This line of thought ran totally counter to 30 years of navy doctrine, and ordinarily, it would have been dismissed.[30] However, this proposal came from the current head of the Combined Fleet, Admiral Isoroku Yamamoto, and could not be easily brushed aside.

Origins of the Pearl Harbor Attack

Yamamoto was opposed to conflict with America. He felt that, given the material and technological strength of the United States, Japan would have no hope of ultimate victory over America. If it came to blows though, Yamamoto would put forth every effort to ensure the goals of his homeland were achieved.[31] He had doubts

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There was disagreement as to the feasibility of the Hawaii Operation from not only the Naval General Staff but also officers within the First Air Fleet staff that would be tasked to carry out the Pearl Harbor attack plan.

whether the Japanese Navy could seize the vast southern areas with the majority of its forces and fend off a flank attack by the US Navy at the same time. The solution that Yamamoto came up with was to take out the Pacific Fleet with one quick action. Then the Southern Operation could proceed unmolested and new Japanese gains consolidated. Yamamoto placed heavy emphasis on aerial warfare because of an earlier posting with the air arm of the Japanese Navy. With the advances the Japanese Navy made in aerial warfare, Yamamoto began contemplating an aerial strike on the fleet at Pearl Harbor. This plan, or the Hawaii Operation as it came to be known, became the means to achieve that goal.[32]

Yamamoto built a planning staff to address the possible Hawaii Operation. One of the first officers tasked was Commander Minoru Genda, the man who brought forth a feasible plan for the strike. Among other things, Genda stressed the need for a surprise attack by a six-carrier task force, which would refuel at sea to make the long voyage. His plan would concentrate the IJN's aerial attack on US Navy carriers and Pearl Harbor's land-based aircraft. These targets were to be the primary ones; other strategic targets—such as the oil storage facilities, drydocks, and so on—were not mentioned at all.[33]

There was disagreement as to the feasibility of the Hawaii Operation from not only the Naval General Staff but also officers within the First Air Fleet staff that would be tasked to carry out the Pearl Harbor attack plan.[34] The plan was finally put before the Japanese Naval General Staff in wargames from 10 to 13 September 1941 at the Tokyo Naval War College. The exercise demonstrated the practicality of the Pearl Harbor attack, but it was felt by the general staff that the chance of the strike force's being detected was too high, thus putting almost all Japan's aircraft carriers at risk.[35] Yamamoto's staff was not deterred. They stressed Yamamoto's argument:

> The present situation—*i.e.*, that of the US fleet in the Hawaiian Islands, strategically speaking—is tantamount to a dagger being pointed at our throat. Should war be declared under these circumstances, the length and breadth of our Southern Operation would immediately be exposed to a serious threat on its flank. In short, the Hawaii Operation is absolutely indispensable for successful accomplishment for the Southern Operation.[36]

Yamamoto's personal feelings were best summed up in a letter to a friend:

> I feel, as officer in command of the fleet, that there will be little prospect of success if we employ the normal type of operations.… In short, my plan is one conceived in desperation … from lack of confidence in a perfectly safe, properly ordered frontal attack; if there is some other suitable person to take over, I am ready to withdraw, gladly and without hesitation.[37]

It was the same argument he used with the Naval General Staff, in a sense "my way or the highway." No one was willing to let the commander in chief resign, so after about a month of deliberations, the plan to attack Pearl Harbor was approved.[38]

Securing the Eastern Flank

Along with the Hawaii Operation, ancillary plans were drawn up to seize the US bases at Wake, Guam, and the Philippines.[39] Occupation of these territories would complement Japanese island holdings in the Central Pacific that were acquired after World War I. These seizures would help build an impregnable barrier against the Americans when such time arose that the US Navy would finally be able to sortie a fleet against the Japanese.

It was a strategy built on sound principles. Because of the Washington Naval Treaty's limitations, the United States was forbidden to build up any bases west of Pearl Harbor. After the Japanese withdrew from the Washington Accords,[40] proposals were made by a Navy board, in late 1938, to beef up its defenses west of Hawaii. However, the appropriations never made it through Congress.[41] Thus, if the Japanese attacked, these bases would fall relatively quickly. This would leave no US bases in the entire Pacific west of Hawaii.[42] Any operations planned by the Navy would have to be run out of and supported from Pearl Harbor.

Time Is Oil

The Japanese felt they had a finite amount of time in which to solve their oil problem. It was decided at the 5 November 1941 Imperial Conference that Japan would go to war with the United States (and Great Britain) if negotiations to break the diplomatic impasse were not successful by 1 December 1941. Guidance from this same meeting directed the Army and Navy to complete plans for the Hawaii and Southern Operations.[43]

The Japanese felt they had a finite amount of time in which to solve their oil problem. It was decided at the 5 November 1941 Imperial Conference that Japan would go to war with the United States (and Great Britain) if negotiations to break the diplomatic impasse were not successful by 1 December 1941.

There were many reasons this stance was adopted at the conference. First, every day the Japanese delayed the Southern Operation, ABCD forces were growing larger. For example, Army strength in Malaya and the Philippines was being reinforced at the rate of 4,000 men every month; air strength and infrastructure were also increasing. It was also feared that the ABCD powers would become closer politically, economically, and militarily in the interim.[44] There was also concern that the Soviet Union possibly would attack Japan in the springtime. If this occurred, the Japanese wanted to be sure the Southern Operation had been completed.[45] Another concern was the weather. The northeast monsoon would make the amphibious landings required in the Southern Operation increasingly difficult after December.[46] It also would affect ships in the Hawaii Operation. Refueling at sea was an absolute necessity for the First Air Fleet to have the range to strike Pearl Harbor. Meteorological studies showed there were only 7 days, on average, that refueling could be accomplished in December.[47] That number could be expected to decrease with the onset of the winter season.

However, the ultimate factor that decided the start of offensive operations was the status of the Japanese fuel stockpile. The Japanese realized that oil was the bottleneck in their fighting strength; any lengthy delay in securing an oil source would be disastrous.[48] Indeed, it was stated at a conference in late October 1941

Oil Logistics in the Pacific War

that Japan needed to occupy the oilfields in the southern areas by March. If this did not occur, adding in such factors as normal stockpile depletion and getting the oilfields back into production, the Japanese would run out of oil in about 18 months.[49] By September 1941, Japanese reserves had dropped to 50 million barrels, and their navy alone was burning 2,900 barrels of oil every hour. The Japanese had reached a crossroads. If they did nothing, they would be out of oil and options in less than 2 years. If they chose war, there was a good chance they could lose a protracted conflict. Given the possibility of success with the second option, versus none with the first option, the Japanese chose war. [50]

There are many critical points of this preconflict period. The Japanese realized the importance of oil to their modern military machine, and any operations undertaken in the vast Pacific theater would require large amounts of oil. They were willing to send a huge task force of irreplaceable ships thousands of miles into hostile waters (and all the attendant oil this operation would consume) to attack a formidable enemy fleet to help achieve oil self-sufficiency.[51] The concurrent plan to seize the US possessions in the Central Pacific would ensure the Japanese would control all the oil-producing regions between the west coast of the United States and the Persian Gulf. Finally, there is the planning of the Pearl Harbor raid; without oil tankers, it would have been impossible for the Japanese Navy to accomplish that mission. Armed with this knowledge, would the Japanese realize this same need for oil applied to the US Navy?

Like the Japanese, the Pacific Fleet had its own oil problems. The only major base for the US Navy in the Pacific was located in Hawaii. All major fleet logistics, repair, and storage were at the naval base at Pearl Harbor. The Navy also suffered from a severe shortage of oilers, which limited the operations radius of the fleet.

Oil, Pearl Harbor, and the US Navy

The thing that tied the fleet to the base [Pearl Harbor] more than any one factor was the question of fuel.

—Admiral Husband E. Kimmel,
***Joint Committee on the Investigation of the Pearl Harbor Attack*[52]**

Like the Japanese, the Pacific Fleet had its own oil problems. The only major base for the US Navy in the Pacific was located in Hawaii. All major fleet logistics, repair, and storage were at the naval base at Pearl Harbor. The Navy also suffered from a severe shortage of oilers, which limited the operations radius of the fleet. The Japanese were well-informed on the strengths and logistics necessities of the Pacific Fleet. With the known vulnerabilities of the Pacific Fleet's logistics train, the Japanese, nevertheless, chose to attack military combatants only, such as the US battleships. This operational strategy was going to come back and haunt the Japanese.

Japanese Intelligence on the US Navy and Pearl Harbor

Extensive intelligence gathering by the Japanese informed them of the abilities, limitations, and makeup of the Pacific Fleet and those areas and facilities required

for its support. No scrap of information was too small. No scrap of information was too small. Detailed intelligence on the Pacific Fleet was the linchpin of the Hawaii Operation.[53]

> The information received from the Japanese after the war shows that their methodical observations and espionage kept them well informed of everything concerning the defenses of Hawaii and the activities of the Pacific Fleet. In our open democratic society Japanese agents were free to observe fleet practices, take photographs with their high-powered equipment, and solicit almost any information desired,… High-powered binoculars were hardly necessary, but they showed particular details, which, in large measure, were unknown even to any single officer of the fleet.[54]

The IJN intelligence officer at Pearl Harbor was Ensign Takeo Yoshikawa. From the spring of 1941, he was in charge of intelligence gathering in Hawaii. Yoshikawa had been studying methods and operations of the Pacific Fleet for the previous 7 years.

> I read a vast amount of material in that period, from obscure American newspapers to military and scientific journals devoted to my area of interest … I studied *Jane's Fighting Ships* and *Aircraft*… devoured the *US Naval Institute Proceedings* and other US books … and magazines…. In addition to this mass of seemingly innocuous information on the Navy and its bases, I had access to the periodic reports of Japanese agents in foreign ports, particularly Singapore and Manila….
>
> In any event, by 1940, I was the Naval General Staff's acknowledged American expert—I knew by then every US man-of-war and aircraft type by name, hull number, configuration, and technical characteristics; and I knew, too, a great deal of general information about the US naval bases at Manila, Guam, and Pearl Harbor.[55]

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It should be noted that the ship information being collected on the west coast also included commercial traffic, especially petroleum shipments. Radio intercepts of Japanese diplomatic messages showed that in mid-1941, Japanese agents operating out of Los Angeles reported the departure of five tankers carrying 400,000 barrels of high-octane fuel to Vladivostok.[56]

The result was a vast intelligence tome, *The Habits, Strengths, and Defenses of the American Fleet in the Hawaiian Area*. In addition, detailed maps of Pearl Harbor were drawn up showing all the information reported above, to include the locations of fuel-storage depots.[57] Yamamoto and the Japanese Navy had the required information to target the Pacific Fleet at Pearl Harbor. Since the purpose of the Hawaiian Operation was to eliminate the Pacific Fleet as a threat, the question was whether Yamamoto would use this information to hit the most vulnerable center of gravity to achieve that goal.

The Primary Targets of the Pearl Harbor Attack Are Ships

On the morning of 7 December 1941, there were 86 ships of the Pacific Fleet in Pearl Harbor. At the end of that day, nine of the ships were sunk or sinking, and ten others were severely damaged in the raid. [58]

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Horrible and devastating as the Pearl Harbor raid was, it was by no means a knockout blow to the Pacific Fleet.

The most important targets among the ships of the Pacific Fleet were the aircraft carriers. Intelligence indicated there would be no carriers in Pearl Harbor that morning, however, so Battleship Row on the east side of Ford Island would be the initial focal point of the raid.[59] The 352-plane raid[60] lasted from 0755, when the first bomb exploded near the seaplane ramp on Ford Island, to approximately 1000 Hawaiian time when the last Japanese planes headed north to their carriers.[61] By the time the raid ended, the Japanese had caused significant injury to the Pacific Fleet; eight battleships, three light cruisers, three destroyers, and four auxiliary vessels were sunk or damaged. There were also major losses among Army and Navy air forces on the island of Oahu and nearly 3,600 US casualties. The Japanese, on the other hand, lost 29 aircraft and 5 midget submarines.[62] Surprise, the key tenet to the success of the Hawaii Operation had been utter and complete.[63]

Horrible and devastating as the Pearl Harbor raid was, it was by no means a knockout blow to the Pacific Fleet. It is true that all eight battleships attacked on 7 December were either sunk or damaged. However, many factors mitigated the overall results of the attack. It is probably most important to note that the majority of sailors, less those who were killed outright in the attack or in the capsized *Oklahoma*, were easily rescued because the attack took place in a relatively small, landlocked harbor. Another factor was the physical state of the ships located on Battleship Row that morning. Professor Thomas C. Hone best stated this condition: "The American battleships were all old; several were nearly overage; most were overweight. None of the battleships in Pearl Harbor was a first-line warship in a material sense; all had recognized deficiencies."[64] They were also a good 10 knots slower than the US aircraft carriers.[65] These details were not unknown to the hierarchy of the Pacific Fleet. When Vice Admiral William F. Halsey was asked whether or not he wanted to take any battleships with him on his reinforcement trip to Wake Island, he retorted "Hell, no! If I have to run, I don't want anything to interfere with my running!"[66] Last, but not least, because of the shallowness of Pearl Harbor, which had an average depth of only 40 feet, all but two battleships eventually would be salvaged.[67] The Japanese were well-aware of the depth of the harbor and the fact some ships would be salvaged. However, the Japanese felt American salvage efforts would take a lot longer than the time required to complete IJN operations in the Southern Area.[68]

Commander Mitsuo Fuchida, airborne leader of the Pearl Harbor attack force, verbally reported strike results to Vice Admiral Chuichi Nagumo after landing on the carrier *Akagi* following the raid:

> Four battleships definitely sunk.… One sank instantly, another capsized, the other two may have settled to the bottom of the bay and may have capsized. This seemed to please Admiral Nagumo who observed, "We may then conclude that anticipated results have been achieved."
>
> Discussion next centered upon the extent of damage inflicted at airfields and airbases, and I expressed my views saying, "All things considered, we have achieved a great amount

of destruction, but it would be unwise to assume that we have destroyed everything. There are still many targets remaining which should be hit."[69]

As far as Nagumo was concerned, though, his primary mission had been accomplished. Now his concern turned to the missing US carriers and their threat to his task force. There was no provision in the Pearl Harbor attack plan to remain in the Hawaiian area to search for US ships not at anchor at the time of attack. Nagumo, who had opposed the Hawaii Operation at its inception, was ready to withdraw. His

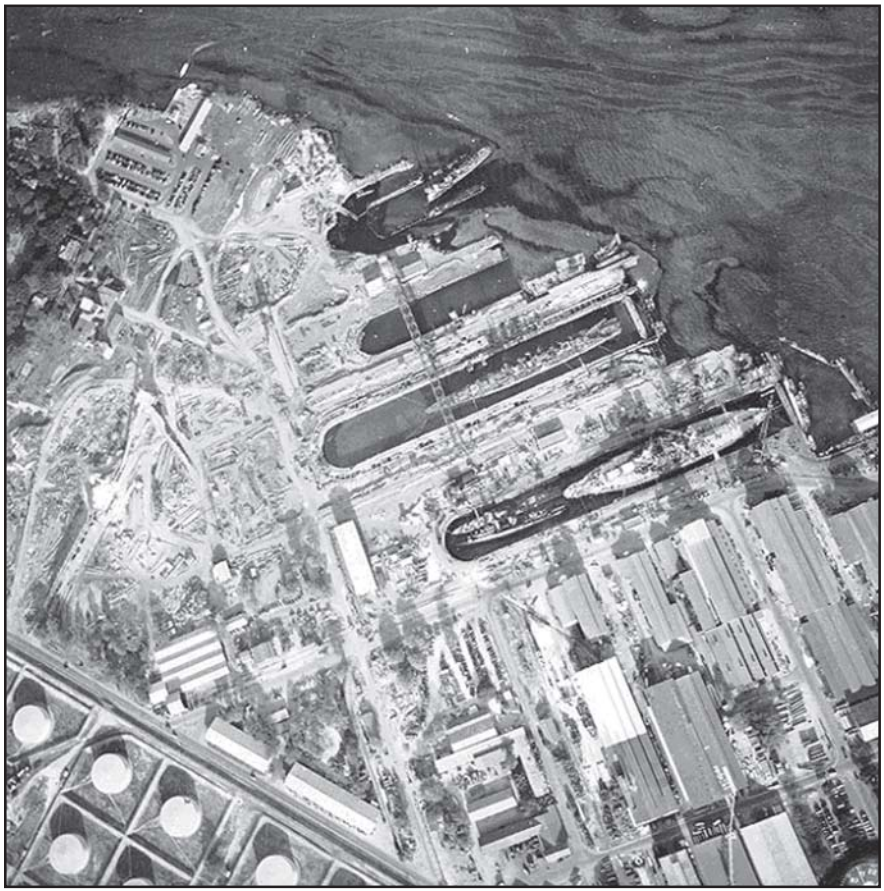

Figure 1. Aerial View of Pearl Harbor Drydock, 10 December 1941. Note the improvised antitorpedo barriers located near the drydock openings. *USS Pennsylvania* and the sunken destroyers *Cassin* and *Downes* are in the lower, No 1, drydock. The **USS *Helena* occupies the middle drydock. The *USS Shaw* and the sunken drydock *YFD-2* are on top. Numerous support shops and base facilities are located in the lower right corner. Also, note the black oil streaks on the harbor surface.** [77]

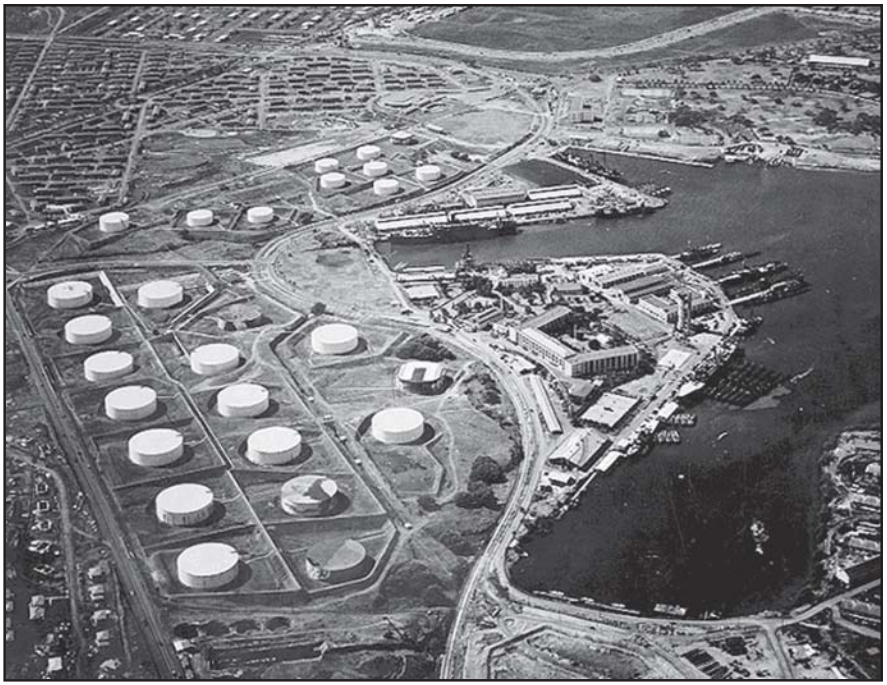

Figure 2. Submarine Base, Pearl Harbor and Adjacent Fuel Tank Farms, 13 October 1941. This is a view of the upper oil tank farm located on the east side of the Pearl Harbor naval base. The lower tank farm was located between Hickam Field and the naval base (see Figure 1 for oil tanks in the lower farm). Note the attempts at camouflage. Two of the tanks in the foreground are painted to resemble terrain features. The third, closest to the submarine base, is painted to resemble a building.[87]

chief of staff, Rear Admiral Jin'ichi Kusaka, had held the same opinion. Kusaka recommended to Nagumo that the fleet withdraw to Japan. Nagumo immediately concurred. A second strike on Pearl Harbor—which would have focused on the dockyards, fuel tanks, and remaining ships—was canceled.[70]

Drydocks, Repair Shops, and Oil Storage Areas Spared

Nagumo did not realize the magnitude of his error in not completing the destruction of Pearl Harbor by attacking the base and fuel facilities. His pedantic and traditional view of naval strategy blinded him to the opportunity of a lifetime.[71] Never again would the Japanese Navy be in a position to deliver such a mortal blow to the US Fleet.[72]

Ironically, the Japanese missed their opportunity to strike at the drydocks during the initial attack. Torpedo bombers approaching from the west over Ford Island

commenced their run on the battleship *Pennsylvania*. Once they came over the island, the Japanese pilots saw that it was moored in drydock No 1. Seeing this, the torpedo bombers shifted their attack runs toward a cruiser, the *USS Helena*, and the destroyer *Ogala* (actually a minesweeper).[73] They would have been served better by attacking the drydocks. Torpedo strikes on the drydock gates would have rendered these essential repair facilities inoperable until those gates were repaired or replaced. It certainly was a fear of the Navy that the Japanese would return and do just that (Figure 1). As can be seen in Figure 1, salvage operations were up and running almost immediately. The targeted specifically. The only bombs that fell near these critical facilities were intended for ships on or near these facilities.[74] Had Nagumo returned with a third wave, he could have leveled the navy yard's support facilities,[75] thereby destroying the Navy's industrial capacity and setting back salvage operations.[76] This oversight would come back to haunt Nagumo in a most personal fashion.

The *USS Yorktown* utilized drydock No 1 after the mauling it had received on the Coral Sea. In a turnaround that can be described nothing short of miraculous, essential temporary repairs were made, and it was sent back out to sea within 72 hours for the critical Midway battle. There, its aircraft were crucial in sending all four of Nagumo's carriers to the bottom of the sea.[78]

By far, the most surprising target oversight of the Japanese attack was the oil and gas storage tanks. The entire fuel supply for the Pacific Fleet was stored in above-ground tanks on the eastern side of the naval base (Figure 2).

As can be seen in Figure 2,, these tanks were perfectly visible to the naked eye; ergo, perfect targets.[79] These tanks were particularly susceptible to enemy action; none of the tanks had bombproof covers.[80] Even a few bombs dropped amongst the tanks could have started a raging conflagration.[81]

Why were these crucial targets not hit? Their loss essentially would have starved the Navy out of the Central Pacific.[82] Did the Japanese not know they were there?

> The Japanese knew all about those oil storage tanks. Their failure to bomb the Fleet's oil supply reflected their preoccupation with tactical rather than logistical targets.… Nagumo's mission was to destroy Kimmel's ships and the airpower on Oahu. If Yamamoto and his advisers chose the wrong targets, or insufficiently diversified ones, the mistake rests on their shoulders.…[83]

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Pearl Harbor Was the Only Filling Station in Town

Pearl Harbor was the only refueling, replacement, and repair point for ships operating in the Hawaiian area.[84] Part of Pearl Harbor's duty of being the Pacific Fleet's chandlery was the stocking and disbursing of oil. To that end, the Navy had just finished restocking its tanks in Pearl Harbor to their total capacity of 4.5 million barrels of oil.[85] The loss of this amount of oil would have effectively driven the Pacific Fleet back to the west coast and effectively knocked almost all ships of the Pacific Fleet out of contention, instead of just 19.[86] The Japanese knew the

Oil Logistics in the Pacific War

importance of oil to a fighting fleet; after all, they had just started a war to achieve a secure source of oil. Why did they not see that the US Fleet needed a secure source of oil if it was to operate in the vast reaches of the Pacific?

Genda later wrote that the question of demolishing the oil tanks only arose after the attack's amazing success. "That was an instance of being given an inch and asking for a mile."[87] He insisted that the objective of the plan was to destroy American warships so they could not interfere with the Southern Operation; oil tanks did not enter into the original idea.

Genda later wrote that the question of demolishing the oil tanks only arose after the attack's amazing success. "That was an instance of being given an inch and asking for a mile."

As no one could charge Genda with lacking either imagination or vision, this uncharacteristic obtuseness could be due only to failure to understand the importance of logistics. Most Japanese naval planners apparently suffered from this same myopia toward the less glamorous necessities of modern warfare.

> The Hawaiian Islands produced no oil; every drop had to be tanked from the mainland. Destruction of the Pacific Fleet's fuel reserves, plus the tanks in which it was stored, would have immobilized every ship based at Pearl Harbor, not just those struck on December 7.… "We had 4-1/2 million barrels of oil out there, and all of it was vulnerable to .50 caliber bullets."[88]

The state of Allied oil supplies in the rest of the Pacific theater was extremely poor. The Japanese rapidly captured the bases at Wake and Guam in pursuit of their Southern Operation goals. This geographically isolated the Philippines and made the US naval base there untenable.[89] A sampling of four other ports in the Pacific highlights this problem. Brisbane had 12,000 tons of fuel available in January 1941, Sydney and Melbourne both had 8,000, and Port Moresby had none. Other bases, in the Netherlands East Indies, for example, could not be counted on for oil supplies because of their proximity to Japanese airpower and imminent Japanese invasion.

Once the Japanese seized the oilfields in the Netherlands East Indies and Burma, they eliminated all potential oil supplies in the Pacific between the Americas and the Middle East.[90]

For the Allies, geography had become almost as a big an enemy as the Japanese.[91] The fuel supplies at Pearl Harbor were crucial for the Navy to bring the war to the Japanese Navy. Admiral Chester W. Nimitz summed up the situation best, "Had the Japanese destroyed the oil, it would have prolonged the war another 2 years."[92]

A Lack of US Oil Tankers

It is interesting to note that only one ship located on Battleship Row on 7 December received no damage at all. Yet, had the Japanese sank or severely damaged this ship, its effect on the Pacific Fleet would have been almost as great a loss as sinking an aircraft carrier. That ship was the fleet oil tanker, *USS Neosho*.[93]

The lack of fleet oilers, like *Neosho*, hung like a large cement albatross around the neck of Navy planners contemplating operations in the Pacific before and after the Pearl Harbor raid.[94] This dearth of oilers was a key vulnerability of the Navy. The Japanese Navy, who had just seen how it would have been impossible to carry

out the Pearl Harbor attack without tanker support, should have targeted these ships that were so crucial to the Navy.

In the years from 1925 to 1940, the quantity of most surface combatants in the Navy had doubled in size; the size of the auxiliary force had not. Although there had been an increase in the number of fleet oilers, they were all kept busy ferrying fuel between bases.[95] On 7 December, the Pacific Fleet had two oilers in Pearl Harbor, three at sea, and six others in ports on the west coast; only four of these were capable of at-sea refueling.[96] This shortage of tankers effectively limited the radius of the Pacific Fleet.[97] It was also a key reason so many ships were located in Pearl Harbor on 7 December. Kimmel was unable to keep less than half his fleet at sea without starting to deplete the oil reserves at Pearl Harbor; his limited supply of oilers could not keep up with the deficit.[98]

Because of this lack of oilers, the fleet could not have even exercised its primary war plan (even if most of its battle line was not at the bottom of Pearl Harbor). The total capacity of the Pacific Fleet's oilers was 760,000 barrels of oil. In the first 9 days after Pearl Harbor, the fleet had expended 750,000 barrels of this sum. Thus, the fleet was tied to its oil supply at Pearl Harbor,[99] and if the Japanese had attacked the oil storage and the associated oilers at Pearl Harbor on 7 December, they would have driven the Pacific Fleet back to the west coast.[100]

If the Pacific Fleet were forced back to the west coast, would it have been effective in opposing the Japanese? The short answer is no, especially if the Japanese began targeting oilers. To give an example, the *USS Lexington* was dispatched from California to assist in the search for Amelia Earhart in July 1937. First, the *Lexington* had to top off its bunkers on the west coast.[101] It then proceeded on a high-speed run of about 30 knots to the Hawaiian Islands. Here, it had to refuel again from the fleet oiler *USS Ramapo* off Lahaina Roads, Maui. The result was that the *Lexington* did not arrive in the search area off Howland Island until 11 days after its departure from the west coast and could not even have done that without the support of the *Ramapo*.[102]

Ships *sortieing* from the west coast would be adding 2,000 nautical miles to their patrols into the Pacific just to get to Hawaii.[103] This number would have to be doubled, obviously, because these same ships would have to get back to the west coast if no oiler support were available and the oil storage at Pearl Harbor no longer existed.

The cruising ranges of the Pacific Fleet simply could not meet this necessity. The best range of the *Yorktown*-class carriers was 12,000 nautical miles at 15 knots, while older carriers had even less endurance.[104] Battleships had much less endurance and were slower. They averaged out at 8,000 nautical miles at 10 knots.[105] Cruisers were a little better off than the carriers; they averaged 14,000-14,500 nautical miles at approximately 15 knots. Destroyers, depending on their class, could go 6,000-9,000 plus nautical miles at 15 knots.[106] Looking at the carriers' and cruisers'

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The Japanese operational strategy of focusing only on symmetric targets, like warships, was adhered to even when asymmetric US vulnerabilities were present.

endurance capabilities, the situation does not seem so bad. However, there are other factors that need to be thrown into the equation.

First, ranges needed to be decreased by a minimum of 15 percent whenever antisubmarine steering measures were taken.[107] Also, a prudent commander might want to avoid a suspected submarine-operating area altogether, if time and circumstances permitted such a detour. This too, would decrease overall endurance. Another factor was ship speeds. Higher speed means more fuel burned. Task force operations require much high-speed steaming for the launch and recovery of aircraft, search tasks, antisubmarine patrol, and so forth. This process, as can be seen by the previous *Lexington* example, burns a prodigious amount of fuel.[108]

The equation all boils down to the availability of oil and sufficient tankers to transport this precious commodity. Kimmel summed up this essential truth when he testified:

> A destroyer at full power exhausts its fuel supply in 30 to 40 hours, at medium speed in 4 to 6 days. War experience has proven the necessity of fueling destroyers every third day, and heavy ships about every fifth day to keep a fighting reserve on board. To have kept the entire fleet at sea for long periods would not have required 11 tankers but approximately 75, with at least one-third of them equipped for underway delivery.[109]

Oil Logistics After Pearl Harbor

The Japanese followed up their attack on Pearl Harbor with submarine operations off the west coast of the United States. These operations were planned to concentrate on striking warships versus logistical support ships and merchantmen. Although the Japanese managed to sink some ships, their submarine operations were a rather feeble effort compared to German U-boat operations against US commercial shipping in the Atlantic. The Germans committed wholesale slaughter along the east coast of the United States after Pearl Harbor. The number of available German submarines for these operations was even less than the Japanese deployment. Yet, the Germans' success was much higher because of their operational strategy of targeting Allied merchantmen, with an emphasis on oil tankers. The Japanese operational strategy of focusing only on symmetric targets, like warships, was adhered to even when asymmetric US vulnerabilities were present. This window of opportunity began to close slowly after Pearl Harbor. The Japanese lost all ability to exploit this weakness by late 1942; by then, they had lost the ability for the offensive, which was never to be recovered.

War Comes to the US West Coast

Japan's geographical situation determined that war in the Pacific would be, in large measure, a war to control the sea so as to exploit its new territorial gains in the Southern Operation. One of the items in its arsenal to help accomplish this task was the submarine.[110]

The overall strategic mission of the Japanese submarine force was to serve as an adjunct to the main battle force. This is to say, when an enemy fleet (the US Pacific Fleet) was bearing down on Japanese waters, the IJN submarines would sortie and intercept the Americans. The Japanese subs would maintain a reconnaissance of the enemy, reporting movements to the Japanese battle fleet, while reducing the enemy force by attrition. When the two fleets met, there would be a great Jutland-style clash that would determine everything.[111] The Hawaii Operation's whole tenet was to nullify the need for this strategy, at least for the first 6 months. However, the submarine was too valuable a tool to be withheld from operations, so the Japanese submarine force was included in the planning of the Hawaii Operation. It would be used for prestrike reconnaissance, to attack targets that escaped the airstrike, and to interdict a counterattacking force.[112] Thirty large fleet boats from the Sixth Fleet were to take part in the attack. Three were to operate as a screen for the Pearl Harbor strike force, 20 others were to position themselves around Oahu, and 5 others each were to carry a two-man midget submarine. The remaining two submarines were to conduct reconnaissance around the Aleutian Islands and other US possessions in the Pacific. Following the attack, 12 of the submarines would remain in the Hawaiian area, and 9 would proceed to the US west coast.[113] There, they were to interdict US lines of communication by destroying enemy shipping.[114]

Although it was part of the original Japanese grand strategy to vigorously prosecute attacks against US commercial shipping, this was not reflected in IJN submarine operations or tactical thought.[115] The Japanese submarines off the west coast of the United States were primarily there to strike at US naval assets.[116] The Japanese hamstrung themselves with their own rules of engagement when it came to merchant traffic. They only were allowed to use one torpedo per merchant ship. Because of this, they often surfaced to engage merchant vessels with their deck guns.[117] This action denied them the use of two of the best weapons the submarine possessed. First, they sacrificed the relative accuracy and lethality of their primary weapon, the torpedo.[118] Second, this tactic sacrificed one of the submarine's greatest commodities—stealth.

Although it was part of the original Japanese grand strategy to vigorously prosecute attacks against US commercial shipping, this was not reflected in IJN submarine operations or tactical thought.

Nevertheless, the Japanese submarines did score some victories on the west coast of the United States The *I-17* damaged one freighter with shell fire and caused the tanker *Emidio* to beach itself off Crescent City, California.[119] The submarine *I-23* attempted a surface attack on another tanker near Monterrey, California, but achieved no hits. The tanker *Agriworld* was able to get off a distress call to the Navy. Two surface attacks by the submarine *I-21* yielded no results. However, its luck was about to change. It torpedoed and sank the tanker *Montebello* 20 miles from Avila, California, on the morning of 23 December. Two other torpedo attacks were made farther down the coast near Los Angeles by *I-19*; one was ineffectual, the other hit the freighter *Absaroka*. With the help of a nearby Navy tug, *Absaroka* was beached right below Fort MacArthur. An order for the subs to shell west coast cities was rescinded at the last minute, and the subs withdrew to Japanese waters in late

December.[120] This order for a premature withdrawal (the subs had hardly made a dent in their torpedo stocks) possibly was due to overconfidence on the part of the Japanese. It was decided to recall subs in the eastern Pacific to support the Southern Operation.[121]

A few more attacks were made on west coast targets later in 1942. One strike that had merit was an attempt to start a large forest fire with bombs dropped by a sublaunched seaplane. Unfortunately for the Japanese, unseasonable rain and fog managed to keep the fire from spreading beyond a small area, and it burned itself out.[122] Another attack against a California oil refinery and tank farm was motivated more by personal than military strategy; in any case, that attack was also ineffectual.[123] From December 1941 to October 1942, Japanese submarines attacked just 19 merchant ships between Hawaii and the west coast; 15 of these were in December 1941.[124]

Overconfidence, poor tactics, and a mentality that stressed commerce and logistical targets were not worthy of destruction let a golden opportunity slip through the Japanese fingers.

Overall, the Japanese submarine campaign on the west coast had meager results. Overconfidence, poor tactics, and a mentality that stressed commerce and logistical targets were not worthy of destruction let a golden opportunity slip through the Japanese fingers.[125] Such would not be the case with their new partners one ocean over.

Roll of the Drums

For reasons probably known only to him, Hitler declared war on the United States on 11 December 1941.[126] For the scope of this article, why he declared war is not important; only the immediate results of that action are reviewed here. The German Navy no longer had any constraints on attacking American shipping. Since he was given such short notice of the imminent declaration of war, Admiral Karl Doenitz, head of Germany's submarine fleet, could only muster five submarines for this first foray into US waters. Operation *Paukenschlag* (Roll of the Drums) effectively began on 12 January 1942 with the sinking of the steamer *Cyclops* by *U-123*, 300 miles off Cape Cod.[127] The primary targets of *Paukenschlag* were to be Allied tankers. As Doenitz summed it up, "Can anyone tell me what good tanks and trucks and airplanes are if the enemy doesn't have the fuel for them?"

Doenitz' *Grey Wolves* fell on Allied shipping as if it was an unprotected flock of sheep. The Germans were aided by the fact the Americans were not at all prepared for what was about to occur. This lack of preparedness aided the Germans, and many mistakes were made. There was no blackout on the east coast, maritime navigational aids were still operating, and ships lacked communications security discipline.[128] From 13 to 23 January 1942, *Paukenschlag* subs sank 25 ships.[129] Seventy percent of the *Paukenschlag* losses were tankers, at an average of 130,000 barrels. If this attrition rate were kept up, the Allies would lose half their tanker fleet in 1 year.[130] The Germans came through *Paukenschlag* without any losses; in fact, not even one German submarine was ever attacked. The American antisubmarine warfare response was pitiful. There existed no plans to deal with the possibility of a submarine assault

and no forces to implement them had they existed.[131] This is ironic because the Atlantic Fleet received 18 destroyers in a transfer from the Pacific Fleet in May 1941.[132]

German submarines eventually sank 391 ships in the western Atlantic, 141 of which were tankers. One quarter of the US tanker fleet was sunk in 1942. Even though US shipyards were beginning to produce new merchant ships in record numbers, there was still a drop in overall available merchant and tanker tonnage. This came at a time when every ship was needed to help support offensives around the globe in a two-ocean war.[133]

Unswerving Devotion to the Decisive Battle Strategy

"The massacre enjoyed by the U-boats along our Atlantic coast in 1942 was as much a national disaster as if saboteurs had destroyed half a dozen of our biggest war plants," wrote Samuel Elliott Morison. Petroleum shipped from the gulf coast to east coast ports dropped fourfold from January 1942 until it began to climb in mid-1943. Tanker tonnage was woefully short.[134]

The Germans, to their credit, realized the importance oil played in the Allies' war plan. As early as 3 January 1942, the Germans were urging the Japanese to concentrate their submarine efforts on a *guerre de course* strategy of commerce warfare. If the two Axis partners could concentrate their submarine efforts on Allied logistics, it would severely limit the Allies' ability to launch any type of offensive.[135] The German naval attache to Japan, Vice Admiral Paul H. Wenneker, repeatedly would urge such a change in strategy. The Japanese would listen courteously, but they were not willing to change their strategy of focusing on warships. Wenneker stated later:

> The Japanese argued that merchant shipping could be easily replaced with the great American production capacity but that naval vessels represented the real power against which they fought and that these vessels and their trained crews were most difficult to replace and hence were the logical targets. If, therefore, they were to hazard their subs, it must be against the Navy.[136]

The Japanese argued that merchant shipping could be easily replaced with the great American production capacity but that naval vessels represented the real power against which they fought and that these vessels and their trained crews were most difficult to replace and hence were the logical targets. If, therefore, they were to hazard their subs, it must be against the Navy.

The Japanese remained slavishly addicted to their decisive battle doctrine. Despite the success of German U-boats off the east coast of the United States (and even their success in World War I), the Japanese would not change their strategy of using subs to support fleet operations.[137]

Unfortunately for the Germans and the Japanese, the Axis alliance was a political arrangement based on self-opportunistic motives. Neither the German nor the Japanese Navy considered mutual cooperation in war planning a matter of much importance when Germany and Japan entered into their alliance with each other.[138]

The Japanese should have concentrated all their submarines off the US west coast oil ports and off Hawaii. While in these patrol areas, the subs should have systematically hunted down and destroyed US tankers and Navy oilers. The Japanese Navy also should have run a shuttle-type operation where some subs could be

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operating in these patrol areas at all times.[139] Had the Japanese followed such a strategy, there would have been much less chance that the Navy would have been able to launch any type of offensive in the Pacific in 1942.

Oil and South Pacific Ops

> During the first year of war in the Pacific, the United States Navy was forced to fight a war that it was unprepared for. It had neither enough ships, storage facilities … nor petroleum. But with a lot of hard work, hasty improvisation, sound leadership, and some honest good luck, it managed (with great difficulty at times) to supply its fighting forces with enough fuel for combat operations. Although the supply system was strained to the breaking point, it never collapsed.[140]

The fuel state in the first half of 1942 was straining the logistics support system to the breaking point.

The fuel state in the first half of 1942 was straining the logistics support system to the breaking point. As previously mentioned, shortly after Pearl Harbor, the Pacific Fleet had, for all purposes, expended almost all the fuel stored aboard its oilers. With the Pacific Fleet's oilers supplying fuel to ships in the Hawaiian area, it meant new supplies were not being brought in from the mainland. Fuel and tankers became so scarce in the spring of 1942 that oil was scavenged from the unsalvageable battleships still resting on the bottom of Battleship Row.[141]

The fuel and tanker shortage became an operational factor almost immediately in the Pacific. The *Neches* was part of Task Force 14 sent to relieve Wake Island in December 1941. *Neches*' slow speed (task forces could proceed only as fast as the accompanying oiler), along with some bad weather, meant the Wake Island relief force was not in position to attack Japanese forces prior to the island's being overrun.[142] A later, planned airstrike by the *Lexington* task force against Wake in January 1942 had to be canceled when the Japanese submarine *I-72* sank that same oiler, *Neches*.[143] Pacific Fleet raids on Japanese-occupied islands in January and February 1942 would have been impossible without support from Navy oilers. In a precursor of events, one carrier raiding force that had *sortied* against Rabaul was forced to retire after the Japanese had discovered it, and much fuel was used up during high-speed maneuvering while fending off Japanese air attacks. The Doolittle raid on Tokyo, which was to have immense strategic implications for the Pacific war, also would not have been possible without tanker support.[144]

The absence of tankers also was becoming a real concern for operations in the South Pacific in early 1942. Although it was merely a question of time before larger IJN forces overwhelmed US and Allied naval vessels during this period of the Southern Operation, the situation was aggravated by the loss of all available ABCD oil sources in that region by mid-February 1942. The loss of the fleet oiler USS *Pecos* to Japanese action exacerbated the situation further.[145]

The lack of fleet oilers also was a secondary factor from the Pacific Fleet's turning from a battleship-centric navy to one formed around aircraft carrier task forces. Even after Pearl Harbor, the Navy still had a sizable battleship force. Seven battleships were available at west coast ports in late March 1942. However, since the Navy

tanker shortage was so acute, there were none available for duty with this force.[146] This force *sortied* on 14 April 1942 to help stem the Japanese advance in the South Pacific. The battleships were loaded down with so much fuel, food, and ammunition that armored belts and decks were below the waterline. If these ships had sailed into harm's way, they would not have lasted long. Fortunately, the Coral Sea action was decided before they could participate, and the force was ordered back to the west coast.[147]

The oilers that could not be spared for the battleships were supporting carrier forces engaged in the Coral Sea. Again, fleet oilers were indispensable to operations. Coral Sea fueling operations were aided by the oilers *Tippecanoe* and *Neosho* (Figure 3).

The fleet oiler *Neosho* supported Task Force 17, led by Rear Admiral J. Jack Fletcher aboard the carrier *Yorktown*. This was the same *Neosho* that was so pointedly ignored by the Japanese during the Pearl Harbor raid. Although sunk by Japanese aircraft on 7 May 1942, the *Neosho* had already played its critical role in dispensing fuel oil to Task Force 17. Had Fletcher needed more fuel, the situation might have gotten a little sticky.[149] Ironically, the Japanese ran into their first fuel problem. A lack of tanker support for their task force, as well as a lack of fuel for its aircraft, caused the Japanese Navy to halt its task force short of its goal, Port Moresby.[150]

Following the miraculous success at Midway, the Pacific Fleet was finally able to go on the offensive in August 1942 with Operation Watchtower, the invasion of Guadalcanal in the Solomon Islands. Inadequate fuel logistics were still a major concern.[151] Fuel and support depots had been set up in Tonga and New Caledonia to support the operation, but they were 1,300 and 500 miles away, respectively, from the action on Guadalcanal.[152]

The lack of fleet oilers also was a secondary factor from the Pacific Fleet's turning from a battleship-centric navy to one formed around aircraft carrier task forces.

Preliminary plans to supply oil for this operation were made based on the past experience of normal operations. The officer in charge of the operation, Admiral Robert L. Ghormely, tried to factor in problems that might arise, such as unforeseen losses or changes in operations. However, his logistics staff was small and had no experience. So a supply of fuel thought to be a comfortable margin for the Guadalcanal operation turned out to be an inadequate amount.[153]

With such a tenuous logistics situation, Operation Watchtower became known derisively as Operation *Shoestring* by the Marines who were surviving on captured enemy rations. Inadequate fuel supplies meant the aircraft carriers covering the Marine landing forces could not stay in place and, after 2 days, withdrew 500 miles to the south to refuel. Operations were touch-and-go on Guadalcanal for the next month. The US position could have been put in jeopardy by a concerted attack on fuel supplies, but this never occurred.[154] In September, Ghormely finally started to get a handle on his logistics requirements, with detailed fuel requests being forwarded up the chain. His actions alleviated much of the fuel problem for the rest of the South Pacific Operation.[155]

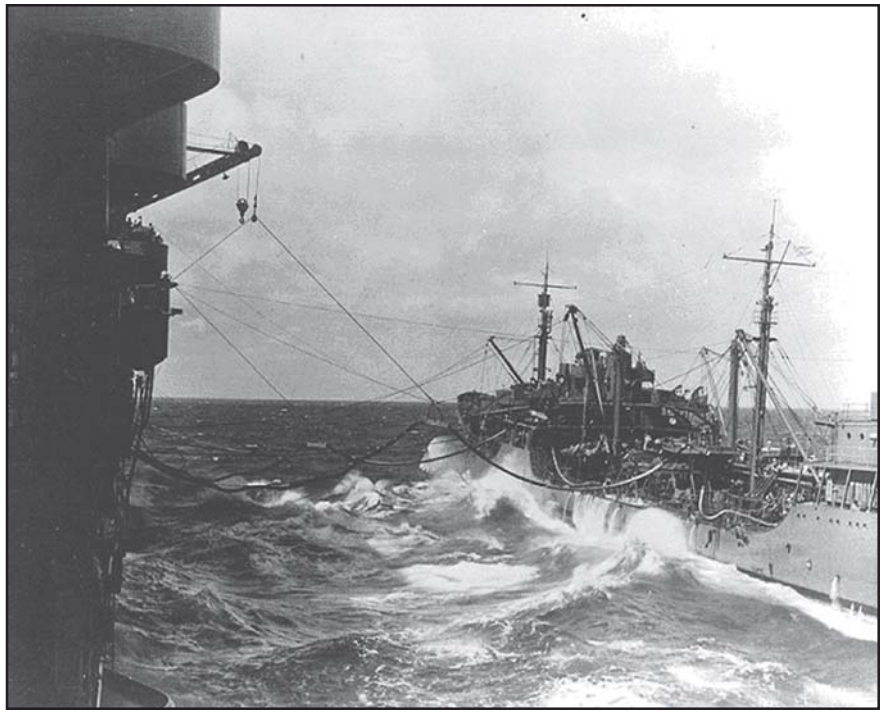

Figure 3. *Neosho* Refueling the *Yorktown*, probably on 1 May 1942. *Neosho* and its escort, the destroyer *Sims*, were sunk by Japanese aircraft on 7 May 1942 after being misidentified as an aircraft carrier and a cruiser. However, by then, the *Neosho* had dispensed enough fuel to Task Force 17 for it to complete its mission of stopping the Port Moresby invasion force. Note the use of the *Yorktown* aircraft crane to support the refueling hose.[148]

With the increase of fuel supplies and the inability of the Japanese to dislodge the Marine defenders on Guadalcanal, the tide had truly begun to turn in the Pacific. From this point on, the Pacific Fleet's fuel situation grew stronger, while the Japanese position grew weaker. The Japanese had lost their opportunity to strike at the key vulnerability of the United States in the Pacific—fuel logistics.

Conclusions

God was on the side of the nation that had the oil.

—Professor Wakimura
Tokyo Imperial University in Postwar Interrogation[156]

The IJN's devotion to an outdated operational strategy, rather than focusing on what effects needed to ensure their national strategy was met, proved to be their downfall.

The Japanese knew that if they did not find a secure and stable source of oil they eventually would have had to comply with US prewar demands. Once it was realized that diplomatic measures would be ineffective, the Japanese plan was to seize and secure as much oil and other resources as possible. The raid at Pearl Harbor was but a branch to achieve that overall goal.

As effective as Japanese intelligence and initial military actions were, they never were focused on the destruction of the key target that might have let them achieve their goal of keeping the Navy out of the Pacific. The Japanese strategic disregard of the fragile US oil infrastructure in the Pacific was an incredible oversight on their part. The Japanese should have attacked the US oil supply at Pearl Harbor and followed up that raid with attacks on US oilers and tankers in the Pacific. Japanese attacks, in conjunction with German strikes, on the oil supply and infrastructure would have bought the Japanese much valuable time—time that could have been used consolidating gains in its newly won territories, time that might have allowed Japan to build up such a defensive perimeter that the cost of an Allied victory might have been too high.

The Japanese were not the first to ignore the importance and vulnerability of logistics. As long ago as 1187, history shows that logistics played a key part in the Muslim's victory over the Crusaders at the Battle of Hittin. The Muslim commander Saladin captured the only water source on the battlefield and denied its use to the Crusaders. The loss of water severely demoralized and debilitated the Crusaders, contributing to their defeat and eventual expulsion from the Holy Land.[157]

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The vulnerability and importance of logistics remains evident today. The terrorist bombing of the destroyer *USS Cole* occurred while it was in port, fueling, at Aden, Yemen, on 12 October 2000. Had it not required fueling, the *USS Cole* would not have put in at Aden, 17 sailors would not have been killed, and the Navy would not temporarily have lost a valuable maritime asset.[158] There is an old saying, "Amateurs talk strategy, and professionals talk logistics." Commanders and their staffs must remember the importance of logistics to achieving the overall goal, for friendly forces as well as the enemy.

Notes

1. Kent Roberts Greenfield, ed, *Command Decisions*, Washington, DC: Office of the Chief of Military History, Department of the Army, 1960, 100-101.
2. Military History Section, Headquarters, Army Forces Far East, Japanese Monograph No 147, *Political Strategy Prior to Outbreak of War, Part III*, Washington, DC: Office of the Chief of Military History, Department of the Army, 1947, 12-13. For a chronological record of these and other events leading up to World War II, see Congress of the United States, *Events Leading Up to World War II*, Washington, DC: US Government Printing Office, 1944.
3. Herbert Feis, The Road to Pearl Harbor, Princeton, NJ: Princeton University Press, 1950, 207.
4. Feis, 206.

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5. *Japanese Monograph No 147*, 25.
6. Akira Iriye, *Pearl Harbor and the Coming of the Pacific War,* Boston: Bedford/St Martin's, 1999, 134. The ABCD powers were defined as the American, British, Chinese, and Dutch governments.
7. *Japanese Monograph No 147*, 28-33.
8. Iriye, 134.
9. *Japanese Monograph No 147*, 42-43.
10. Iriye, 136.
11. Eric Larrabee, *Commander in Chief*, New York, NY: Harper & Row, 1987, 46.
12. *Papers Relating to the Foreign Relations of the United States, Japan: 1931-1941*, Vol II, Washington, DC: United States Government Printing Office, 1943, 266.
13. Iriye, 145.
14. Robert Goralski and Russell W. Freeburg, *Oil and War*, New York, NY: William Morrow and CO, 1987, 101.
15. *Foreign Relations of the United States. Diplomatic Papers, 1941, Vol IV, The Far East,* Washington, DC: United States Government Printing Office, 1956, 840.
16. Goralski, 101.
17. Feis, 268.
18. Nobutaka Ike, *The International Political Roots of Pearl Harbor: The United States-Japanese Dyad, Translations of the Records of the Liaison Conferences 19 through 75;* and *Four Imperial Conferences*, report to Dr Thomas W. Milburn, Behavioral Sciences Group, China Lake, CA: United States Naval Ordnance Test Station, 30 Mar 64-15 Jun 65, 16-17.
19. *Japanese Monograph No, 147*, 46-48.
20. Iriye, 128.
21. *Papers Relating to the Foreign Relations of the United States*, *Japan: 1931-1941,* Vol II, 137-143. In this correspondence, the Counselor of the US Embassy in Tokyo related to the Japanese Vice Minister for Foreign Affairs that any nation that was to prejudice British lines of communication could expect to come into conflict with the United States. When asked by the Japanese minister that if the Japanese attacked Singapore there would be war with the United States, the counselor replied that the situation would "inevitably raise that question." The US Ambassador, Joseph Grew, later confirmed this position to the Japanese Prime Minister.
22. Congress of the United States, Hearings before the Joint Committee on the Investigation of the Pearl Harbor Attack, Part 6, Washington, DC: US Government Printing Office, 1946, 2866.
23. *Papers Relating to the Foreign Relations of the United States, Japan: 1931-1941,* Vol II, 556-557. It is interesting to note that, although these were rather explicit warnings sent by Roosevelt to the Japanese, Roosevelt himself questioned whether the United States had the political will to back them up. When asked by the Chief of Naval Operations, Adm H. R. Stark, what the US response would be in the event of an attack on British possessions in the Far East, Roosevelt responded, "Don't ask me these questions." See *Investigation of the Pearl Harbor Attack, Part 5,* 2231-2232.
24. Feis, 190.
25. Kent Roberts Greenfield, ed, *Command Decisions*, 106; also see Larrabee, 91.
26. Military History Section, Headquarters, Army Forces Far East, Japanese Monograph No 150, *Political Strategy Prior to Outbreak of War Part IV*, Washington, DC: Office of the Chief of Military History, Department of the Army, 1947, 1.
27. Nobutaka Ike, *The International Political Roots of Pearl Harbor,* Imperial Conference, 6 Sep 1941, 33-34.

28. John Buckley, *Air Power in the Age of Total War*, Bloomington, IN: Indiana University Press, 1999, 95.
29. Dr David C. Evans, *The Japanese Navy in World War II*, 2d ed, Annapolis MD: Naval Institute Press, 1986, 8-9.
30. Hiroyuki Agawa, *The Reluctant Admiral*, New York, NY: Kodansha International, 1979, 197-198. The author relates two stories: one that shows how independent operational thought that ran counter to naval general staff policy was frowned upon. He also relates an incident during fleet map maneuvers that showed minor trivialities, such as logistics, could be discounted if overall results were negative to the desired outcome.
31. Gordon W. Prange, *At Dawn We Slept: The Untold Story of Pearl Harbor*, New York, NY: McGraw-Hill, 1986, 10.
32. Prange, *At Dawn We Slept,* 12-14.
33. Prange, *At Dawn We Slept,* 20-28.
34. Shigeru Fukudome, "Hawaii Operation," *US Naval Institute Proceedings*, Dec 1955, 1318. It is interesting to note that the two men who were to carry out the tactical part of the plan at Pearl Harbor—Nagumo and his chief of staff, Rear Adm Ryunosuke Kusaka—felt that the Hawaii Operation was too risky, and this apprehension stayed with them throughout the planning and execution of the attack. See also Agawa, 263-264.
35. *Command Decisions*, 109.
36. Fukudome, 1320.
37. Agawa, 235. This letter was written after the Naval General Staff approved the Pearl Harbor attack plan.
38. *Ibid*.
39. Military History Section, Headquarters, Army Forces Far East, Japanese Monograph No 152, *Political Strategy Prior to Outbreak of War, Part V,* Washington, DC: Office of the Chief of Military History, Department of the Army, 1947, 50-51.
40. *Events Leading up to World War II*, 54.
41. Senator David I. Walsh, *The Decline and Renaissance of the Navy 1922-1944*, Washington, DC: US Government Printing Office, 1944, 4-7.
42. Arthur Zich, *The Rising Sun*, Alexandria, Virginia: Time-Life Books, 1977, 87 and 89-97. When the Japanese attacked Guam on 10 Dec 1941, the garrison of a little more than 425 men surrendered in less than 1 day. When attempts were made to increase the defenses of Wake and the Philippines in the second half of 1941, it was too little, too late. Wake fell on 23 Dec 1941. Although the Philippines took longer to conquer (the Americans didn't formally surrender until 6 May 1942), their demise was a forgone conclusion. The United States could not relieve the Philippines because there were no reinforcements available and no way to protect them even if they were.
43. The International Political Roots of Pearl Harbor, Imperial Conference, 5 Nov 1941, 22-23.
44. *Japanese Monograph No 150*, 87-88.
45. *Japanese Monograph No 147*, 15.
46. Ronald Spector, *Eagle Against the Sun,* New York, NY: The Free Press, 1985, 83.
47. Fukudome, 1319.
48. *The International Political Roots of Pearl Harbor*, Imperial Conference, 6 Sep 1941, 37.
49. *Japanese Monograph No 150*, 20.
50. Goralski, 102.
51. Gordon W. Prange with Donald M. Goldstein, and Katherine V. Dillon, *Pearl Harbor: The Verdict of History,* New York, NY: McGraw-Hill, 1986, 490.

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52. *Investigation of the Pearl Harbor Attack*, *Part 6,* 2569.
53. Prange, *Pearl Harbor: The Verdict of History*, 482.
54. Homer N. Wallin, *Pearl Harbor: Why, How, Fleet Salvage and Final Appraisal,* Washington, DC: Naval History Division, 1968, 60.
55. Takeo Yoshikawa and Norman Stanford, "Top Secret Assignment," *US Naval Institute Proceedings,* Dec 1960, 27-29 and 33.
56. Goralski, 85.
57. John Costello, *The Pacific War,* New York, NY: Quill, 1982, 84.
58. Homer N. Wallin, "Rejuvenation at Pearl Harbor," *US Naval Institute Proceedings*, Dec 1946, 1521-1523. This total includes the floating drydock, YFD-2. It is also important to note that there were many ships of the Pacific Fleet that were not in Pearl Harbor that Sunday. For example, the carriers *Enterprise* and *Lexingto*n were ferrying USMC aircraft to Wake and Midway Islands in anticipation of war starting in the Pacific. Numerous other ships were patrolling in the Pacific or were in ports on the west coast.
59. Prange, *At Dawn We Slept*, 25 and 374. An interesting note of controversy exists over the primacy of battleships versus aircraft carriers as the primary targets of the Pearl Harbor raid. Genda had been pushing for carriers as the primary targets since February 1941. Testimony made by Capt Mitsuo Fuchida during his interview with the US Strategic Bombing Survey team backs up Genda's statement (see *United States Strategic Bombing Survey* [Pacific], Interrogations of Japanese Officials, No 72, Vol I, 122. However, those statements do not jibe with "Carrier Striking Task Force Operations Order No 3" sent to the Pearl Harbor attack force on 23 Nov 1941 (see Japanese Monograph No 97, *Pearl Harbor Operations: General Outline and Orders and Plans,* 14). In this order, Yamamoto specifies that both battleships and carriers will be attacked but battleships will be the priority targets for the first wave of attacking aircraft. Carriers were the priority of the second wave. Although the Japanese knew there were not any carriers in Pearl Harbor as of 6 Dec, there was a chance that one or more might return that night. "If that happens," said Genda, "I don't care if all eight of the battleships are away." "As an airman," remarked Oishi (Nagumo's senior staff officer), "you naturally place much importance on carriers. Of course, it would be good if we could get three of them, but I think it would be better if we get all eight of the battleships." (See Mitsuo Fuchida, "I Led the Air Attack on Pearl Harbor," *US Naval Institute Proceedings*, Sep 1952, 944). Since no carriers did come into Pearl Harbor during the night of 6-7 Dec, the point is moot. However, it does give insight to the prioritization of potential targets in the eyes of the IJN leadership. It also gives pause to wonder what those Japanese airmen would have targeted first if the carriers had been in Pearl Harbor.
60. Fuchida, 945 and 951.
61. Prange, *At Dawn We Slept*, 506 and 538.
62. Prange, *At Dawn We Slept*, 539-540.
63. Prange, *At Dawn We Slept*, 25 and 503-504.
64. Prange, *Pearl Harbor: The Verdict of History*, 537.
65. Spector, 147.
66. Prange, *At Dawn We Slept*, 401.
67. Wallin, "Rejuvenation at Pearl Harbor," 1521. In addition, the target battleship *Utah* was not raised because of her age and the time and effort salvage would entail. Although she tends to be overshadowed by the memorial of her sister ship *Arizona* and the USS *Missouri* floating museum, a small monument to the *Utah* and the 58 men still entombed can be found on the west-northwest shore of Ford Island behind a family housing area. See also E. B. Potter, ed, *Sea Power—A Naval History*, Englewood Cliffs, NJ: Prentice-Hall, 1960, 651, for information on the *Arizona* and *Oklahoma*. Also, because of the shallow depth of the harbor, the Japanese had worked feverishly to develop a torpedo that would not dive to 60

feet before leveling out. By the addition of wooden stabilizers, they only were able to solve this problem in Oct 1941 (see Prange, *At Dawn We Slept*, 160 and 321).

68. Prange, *At Dawn We Slept*, 374. The Japanese Ambassador to the United States, Nomura, who had no fore knowledge of the Pearl Harbor attack, saw this as a key tactical flaw in the Hawaii Operation (see Prange, *Pearl Harbor: The Verdict of History*, 538).
69. Fuchida, 952.
70. Prange, *At Dawn We Slept*, 542-545.
71. Prange, *At Dawn We Slept*, 545.
72. Evans, 40.
73. Fuchida, 950. See also Wallin, *Pearl Harbor: Why, How, Fleet Salvage and Final Appraisal*, 141.
74. Wallin, "Rejuvenation at Pearl Harbor," 1524.
75. In defense of Nagumo, machine and repair tools were notoriously hard to destroy. Industrial plants targeted by the US Army Air Forces in Europe would be destroyed, but the machine tools inside the buildings showed more durability. See the *United States Strategic Bombing Survey*, Maxwell AFB, AL: Air University Press, 1987, 15, 17-18.
76. Wallin, *Pearl Harbor: Why, How, Fleet Salvage and Final Appraisal,* 175. The salvage and repair operations at Pearl Harbor were nothing short of Herculean. A short summary will show the reader how quickly some temporary repairs were made. The *Pennsylvania* sailed to the west coast 2 weeks after the attack. The *Maryland* and *Tennessee* were ready for combat the same day. The destroyer *Shaw*, whose bow was blown off in a spectacular explosion, left for California under her own steam on 9 February 1942. The *Nevada,* which Nimitz doubted would ever sail again, was in drydock by mid-February and en route to the west coast by mid-April (see Prange, *Pearl Harbor: The Verdict of History*, 538-539).
77. Naval Historical Center, Department of the Navy, Various photographs, 40-41. [Online] Available: http://www.history.navy.mil/photos/images, Feb 2001. Drydock photos [Online] Available: http://www.history.navy.mil/photos/images/g380000/g387598c.htm.
78. Robert Cressman, *That Gallant Ship USS Yorktown* CV-5, Missoula, MT: Pictorial Histories Publishing Co, 1985, 115, 117, and 118. To be filed under the heading of ironic justice, all four carriers had participated in the Pearl Harbor attack; see Gordon W. Prange's *Miracle at Midway*, New York, NY: McGraw-Hill, 1982, for an excellent review of that conflict.
79. *Investigation of the Pearl Harbor Attack, Part 6*, 2570. The upper tank farm was clearly visible next to the southeast loch of Pearl Harbor as Figure 2 shows. The lower tank farm was next to the Hickam Field water tower, an approximate 150-foot high obelisk, that was visible from up to 5 miles away (see *Investigation of the Pearl Harbor Attack*, *Part 38,* Item 117).
80. *Investigation of the Pearl Harbor Attack*, *Part 6,* 2812.
81. Wallin, "Rejuvenation at Pearl Harbor," 1524. The Navy realized the vulnerability of the oil supply and was in the process of building some underground storage tanks; however, these would not be completed until late 1942 (Gunter Bischof and Robert L. Dupont, ed, *The Pacific War Revisited*, Baton Rouge, Louisiana: Louisiana State University Press, 1997). There was to be a total of 15 underground tanks (100 feet wide by 285 feet high) with a storage capacity of approximately 4.5 million barrels, the same amount as the above-ground tanks. See I*nvestigation of the Pearl Harbor Attack, Part 23*, 966. Also see William M. Powers, "Pearl Harbor Today," *US Naval Institute Proceedings*, Dec 1981, 52.
82. Prange, *Miracle at Midway*, 4.
83. Prange, *Pearl Harbor: The Verdict of History*, 485.
84. *Investigation of the Pearl Harbor Attack*, *Part 6,* 2506.
85. Goralski, 154. It should be noted that there are several discrepancies in the total amount of fuel in storage and total capacity available at Pearl Harbor on 7 Dec 1941. Kimmel testified that there were 4 million gallons in storage (see *Investigation of the Pearl Harbor Attack, Part 6,* 2812). Adm Claude C. Bloch, commander of the 14th Naval District at the time of the

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attack, testified to the Hart Commission that there were approximately 4 million barrels in storage that morning (*Investigation of the Pearl Harbor Attack, Part 26*, 101). Goralski states that there were 4.5 million barrels stored. Since the purpose of the inquiries following the Pearl Harbor attack were to find out why the US Armed Forces on Hawaii were caught unawares and Goralski's work is more focused on the role of oil in war, his numbers will be used.

86. *Investigation of the Pearl Harbor Attack*, *Part 6,* 2570.
87. Photos [Online] Available: http://www.history.navy.mil/photos/images/g100000/g182880c.htm. The earthen berms located between the tanks were used to contain potential oil spills.
88. Prange, P*earl Harbor: The Verdict of History*, 509-510. The quote at the end is from Nimitz.
89. Duncan S. Ballantine, *US Naval Logistics in the Second World War*, Newport, RI, Naval War College Press, 1998, 39. Japanese aircraft destroyed the Cavite naval base on 10 Dec 1941 (see *Dictionary of American Naval Fighting Ships,* Vol VII, Washington, DC: Naval Historical Center, Department of the Navy, 1981, 282).
90. Bischof and Dupont, 61-62.
91. Bischof and Dupont, 43. By Mar 1942, at least one navy tanker was sent to Abadan, Iran, to get oil to support operations in the South Pacific (see D*ictionary of American Naval Fighting Ships*, Vol VII, 282).
92. Prange, *Pearl Harbor: The Verdict of History*, 510.
93. Wallin, *Pearl Harbor: Why, How, Fleet Salvage and Final Appraisal,* 103-104. Also see Commanding Officer *USS Neosho*, "Report on Raid on Pearl Harbor, T. H., 7 Dec 1941 [Online] Available: http://www.ibiblio.org/hyperwar/USN/ships/logs/AO/ao23-Pearl.html, 5 Mar 2001.
94. Bischof and Dupont, 57. The Navy classified its oil tankers as fleet oilers. For the purposes of this article, Navy oilers is synonymous with tanker or oil tanker.
95. Ballantine, 4.
96. *Investigation of the Pearl Harbor Attack*, *Part 6*, 2504. Also see *Investigation of the Pearl Harbor Attack, Part 12*, 345-346. In addition, there were two other oilers in the Cavite Navy Yard the morning of the Pearl Harbor attack; they were attached to US Asiatic Fleet (see *Dictionary of American Naval Fighting Ships,* Vol VII, 282).
97. Prange, *Pearl Harbor: The Verdict of History*, 547.
98. *Investigation of the Pearl Harbor Attack*, *Part 6,* 2504, 2569, and 2732.
99. *Investigation of the Pearl Harbor Attack*, *Part 32,* 593.
100. *Investigation of the Pearl Harbor Attack*, *Part 6,* 2570. The Japanese knew the oilers were in Pearl Harbor; the Japanese consulate kept them informed on all ship arrivals and departures (see Fuchida, 943). The Japanese attack force made a conscious decision to not attack the *Neosho*. She was berthed at the F-4 fueling dock at Ford Island. In their planning, the Japanese had a torpedo bomber of the initial strike force tasked against the ship in this berth (torpedo track 3); the *Neosho* was not torpedoed. Later, when the *Neosho* was backing up the East Loch of the harbor, she was purposefully not attacked by a Japanese bomber who held its fire in order to strike the battleship *Nevada*. Strangely, the oiler at the F-4 berth was marked as sunk in Fuchida's post battle report (see Prange, *At Dawn We Slept*, 385, 512, 518, and 536). The Japanese were also aware that there were two oilers at Cavite; they even knew their names (see *Investigation of the Pearl Harbor Attack, Part 12,* 302-303). It is also a fair assumption that the Japanese knew the locations of the other oilers that were in port on the west coast on 7 Dec 1941.
101. B. Orchard Lisle, "The Case for Aircraft-Carrying Oil Tankers," *US Naval Institute Proceedings*, Nov 1942, 1555. There is debate on where Lexington departed from on the west coast, but there was a delay in her departure. Given the desire among naval officers to have as much fuel in their bunkers as possible, with time available to the *Lexington* prior to her departure from the west coast, it is assumed she topped off her fuel bunkers.

102. Susan Butler, *East to the Dawn*, Reading, Massachusetts: Addison-Wesley, 1997, 414. Also see Elgen M. Long and Marie K. Long, *Amelia Earhart,* New York, NY: Simon & Schuster, 1999, 220. Ironically, the *USS Ramapo* was the other oiler at Pearl Harbor the morning of 7 Dec 1941 (see *Investigation of the Pearl Harbor Attack*, *Part 12,* 348-349); also see *Commanding Officer USS Ramapo*. "Report on Raid on Pearl Harbor," 7 Dec 1941 [Online] Available: http://www.ibiblio.org/hyperwar/USN/ships/logs/AO/ao12-Pearl.html, 5 Mar 2001.
103. Ballantine, 40.
104. Roger Chesnau, *Aircraft Carriers of the World*, *1914 to the Present*, Annapolis, MD: Naval Institute Press, 1984, 201, 205, and 206.
105. Ian Sturton, ed, *Conway's All the World's Battleships 1906 to the Present,* Annapolis, Maryland: Naval Institute Press, 1987, 160, 164, 168, 172, and 176.
106. James C. Fahey, *The Ships and Aircraft of the US Fleet*, New York, NY: Ships and Aircraft, 1945, 15, 18, 23-25.
107. "The Zig-Zag Course as a Defence Against Submarines," *US Naval Institute Proceedings*, Professional Notes, Aug 17, 1836. Although a dated article, this technique, which was a proven defense at the end of World War I, could be expected to be used at the start of World War II.
108. Bischof, 70.
109. *Investigation of the Pearl Harbor Attack*, *Part 6,* 2504.
110. *Strategic Bombing Survey*, 108.
111. Norman Polmar and Dorr Carpenter, *Submarines of the Imperial Japanese Navy,* Annapolis, MD: Naval Institute Press, 1986, 1.
112. Polmar and Carpenter, 12-13. Also see Potter, 796.
113. Polmar and Carpenter, 13-14. The midget submarines were to attack US warships in Pearl Harbor in conjunction with the air raid. Following the attack, none of the five midget submarines ever made it back to the mother ship.
114. Military History Section, Headquarters, Army Forces Far East, Japanese *Monograph No 108, Submarine Operations in the First Phase Operations, December 1941 to April 1942,* Washington, DC: Office of the Chief of Military History, Department of the Army, 1947, 1.
115. Japanese Monograph N. 150, *Political Strategy Prior to Outbreak of War, Part IV*, 47.
116. Polmar, 11. The prewar strategy of the primary role of fleet attack remained unchanged until Apr 1942. After this point, submarines switched to commercial shipping; however, most of these attacks seemed to concentrate in the Indian Ocean area, which had minimal effect on Pacific Fleet operations.
117. Donald J. Young, "For a week in December 1941, Japanese submarines prowled the Pacific coastline, searching for merchant ships to sink," *World War II*, Jul 1998.
118. William Scheck, "Japanese submarine commander Kozo Nishino gained personal satisfaction from shelling the California coast." *World War II*, Jul 1998, 18. Among other items, the article mentions the difficulty of keeping the submarine deck gun trained on targets while the submarine was constantly moving. Also the Japanese torpedo, a 24-inch, oxygen-driven weapon, had characteristics that more than doubled the nearest US model (see Prange, *At Dawn We Slept*, 394).
119. Young, "For a week in December 1941, Japanese submarines prowled the Pacific coastline, searching for merchant ships to sink," 27-29. It should be noted that the *I-17* attempted to shell the *Emidio* first, and the tanker was able to send out a distress call. Responding aircraft were able to drop depth charges on the sub—twice. Although the sub suffered no damage, the surface attack shows the increased risk the Japanese took.
120. Young, 29-32.
121. Carl Boyd and Akihiko Yoshida, *The Japanese Submarine Force and World War II,* Annapolis, MD: Naval Institute Press, 1995, 68-69.
122. William H. Langenberg, "A floatplane launched from an Imperial Japanese Navy submarine dropped its bombs in September 1942—the first time the continental United States was bombed

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from the air." [Online] Available: http://www.theistorynetcom/AviationHistory/articles/1998/11982_text.htm, 7 Mar 2001.

123. Scheck, "Japanese submarine commander Kozo Nishino gained personal satisfaction from shelling California coast," 16-18. The sub commander Kozo Nishino had visited the refinery during the prewar period as the commander of a Japanese tanker. In a welcoming ceremony, he slipped on some oil and ended up in a cactus patch, much to the amusement of local refinery workers. Nishino, insulted by the laughter, saw his chance to get revenge in February 1942. He peppered away at the refinery for 45 minutes with his 5.5-inch gun. He did not cause any significant damage, but apparently, it was enough to settle a personal score.
124. Juergen Rohwer, *Axis Submarine Successes 1939-1945,* Annapolis, Maryland: Naval Institute Press, 1983, 278-281.
125. Potter, 799.
126. *Events Leading up to World War II*, 310.
127. Ladilas Farago, *The Tenth Fleet,* New York, NY: Ivan Oblensky Inc, 1962, 46-47, 55.
128. Goralski, 103-104.
129. Farago, 58. Estimates range from 25 to 44 ships sunk, depending on the source. It should also be note that the Germans sank 74 ships within 300 miles of the American coast in Mar 1942 alone; again, a high proportion of these were tankers. Losses were so bad that if the rate continued there would not be enough fuel to carry on the war (see also Goralski, 106-112).
130. Goralski, 106.
131. Farago, 58
132. *Investigation of the Pearl Harbor Attack*, *Part 6,* 2505. The destroyers (along with other ships transferred) were to be used in neutrality patrols to keep German naval forces out of the western Atlantic.
133. Goralski, 116.
134. Goralski, 109-111. The tanker shortage became so acute that some Liberty-type dry cargo ships were converted into tankers with most being delivered in 1943 (see L. A. Sawyer and W. H. Mitchell, *The Liberty Ships,* Cambridge, MD: Cornell Maritime Press, 1970, 161.
135. *International Military Tribunal for the Far East,* Vol 256, Tokyo, Japan, 1 Dec 1947, 34257.
136. Goralski, 186-188.
137. Potter, 796.
138. John W. Masland, "Japanese-German Naval Collaboration in World War II," *US Naval Institute Proceedings*, Feb 1949, 179 and 182.
139. Boyd and Yoshida, 189-190.
140. Bischof and Dupont, 78.
141. Wallin, "Rejuvenation at Pearl Harbor," 1545. About 1 million gallons of oil were recovered from the Oklahoma alone.
142. Bischof and Dupont, 66.
143. Bischof and Dupont, 77.
144. Worrall R Carter, *Beans, Bullets, and Black Oil,* Newport, RI: Naval War College Press, 1998, 17-20. The raid was a boost for American morale after a steady diet of defeat. It also confirmed to Yamamoto the need for the upcoming Midway operation, where the defeat of the Japanese Navy later proved to be the turning point in the Pacific war (see Prange, *Miracle at Midway*, 24-27).
145. Carter, 15-16. The *Pecos* was attempting to join her sister ship *Trinity* in the Persian Gulf when she was sunk. The oil situation became so critical that the Australian cruiser *Hobart* could not participate in the Java Sea battle on 27 February 1942 because of a lack of fuel. Another factor in fueling operations was the excruciating pace of refueling operations. The 1938 standard tanker could pump only 200 tons of fuel per hour. The newer T-2 tankers could pump approximately 700 tons an hour. At the end of 1941, the Navy only possessed six of these T-2 types (Cimarron class) with four in the Pacific Fleet (see Lane C. Kendall, "Tanker Operation and Management," *US Naval Institute Proceedings*, Apr 1957, 425. Also see Fahey, 48.

146. Spector, 158 and 168.
147. Carter, 11.
148. Photos [Online] Available: http://www.history.navy.mil/photos/images/g460000/g464653c.htm. Also see Carter, 20-21, and see Zich, 69.
149. Carter, 21.
150. Goralski, 156. This was the first time the Japanese were to run into a fuel supply problem. It was an awful portent of the IJN's future operations.
151. George C. Dyer, The Amphibians Came to Conquer: The Story of Admiral Richmond Kelly Turner, Washington, DC: US Government Printing Office, 1972, 311-312.
152. Carter, 21, 23-24.
153. Carter, 24-25.
154. Goralski, 157. Japanese bombing and naval gunfire came close to putting the US airstrip Henderson Field out of action when critical fuel supplies were destroyed. Another time, the arrival of four tankers was said to have turned the battle, "If they hadn't arrived when they did, we wouldn't have Guadalcanal" said Ghormely.
155. Carter, 28, 30, and 32.
156. Goralski, 304.
157. Gerard Chaliand, ed, *The Art of War in World History,* Los Angeles, CA: University of California Press, 1994, 400-404.
158. Speaker remarks and press coverage. Lecture to AY 2001 students and faculty, Air Command and Staff College, Maxwell AFB, Alabama, 15 Mar 2001.

Lieutenant Colonel Jon M. Sutterfield, USAF

How Logistics Made *Big Week* Big: Eighth Air Force Bombing, 20-25 February 1944

The night of 19 February 1944 found England shrouded under a heavy cloud cover, but the weather over Germany was breaking. While the murk might complicate getting away and possibly landing, General Spaatz had made his decision—"Let 'em go."[2] What was to be called the Big Week (20-25 February 1944) had begun. The next day, 20 February, saw the largest force of aircraft up to that time take off and head for targets in Germany. England literally shook under the roar of engines—some 1,004 bomber aircraft plus their fighter escorts.[3]

The primary objective of Big Week was to direct a strategic bombing campaign against the Luftwaffe that would destroy its means to continue the war and, as a result, gain air superiority before Operation Overlord.[4] Bomber operations were conducted principally by the Eighth Air Force, with support from both the Fifteenth Air Force and the Royal Air Force (RAF). In-theater logistics support, the key element that allowed the Eighth Air Force to kick off Big Week, came from the VIII Air Force Service Command (AFSC). An order of magnitude measure of this logistics effort is seen in the number of bomber aircraft generated—VIII AFSC made 1,292 bombers available, an unprecedented number. However, many other facets of logistics support, often on a scale never seen before, were also necessary for Big Week. These include preparation—industrial mobilization, unit buildup and beddown, stateside logistics support, facility expansion and modernization, training and equipping of personnel, and organization of air logistics activities. As is often the case, much of the planning, preparation, and execution of the Eighth's bombing operations was subject to uncertainties that made logistics support difficult and required improvisation on the part of both logistics organizations and logistics leadership.[5]

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The Industrial Mobilization Plan of 1924 called for instantaneous industrial mobilization upon declaration of war (M-day), based on the assumption that civilian leadership would not accept gradual mobilization prior to a declaration of war, and for military control of the economy. The plan was revised in 1934.

The Foundations of Eighth Air Force Logistics

Armies do not go out and have a fight and one guy wins and the other loses and the winner takes all. Throughout history victorious commanders have been those that knew logistics when they saw it. Before any plans can be made to provide an army, logistics must be provided first. History has changed a lot, but logistics has been the crux of every one of these changes, the nail that was missing, which lead to the loss of a country lead to a lot of those decisions.[6]

—Major General Hugh J. Knerr, USAAF

Industrial Mobilization Planning

Organizations and planning that focused on industrial mobilization were primarily the result of the *National Defense Act of 1920* and the *Industrial Mobilization Plan of 1924*. The Defense Act established the War Department Planning Branch, Army and Navy Munitions Board, and Army Industrial College. It also directed the Assistant Secretary of War to prepare mobilizations plans. The Industrial Mobilization Plan of 1924 called for instantaneous industrial mobilization upon declaration of war (M-day), based on the assumption that civilian leadership would not accept gradual mobilization prior to a declaration of war, and for military control of the economy. The plan was revised in 1934. A variety of flaws plagued mobilization planning efforts and the 1934 plan itself. These include incorrect assumptions (no civilian support for gradual mobilization), not addressing the needs of the civilian populace or potential allies, and military control of the civilian economy. Further, the operations staff that prepared the plan failed to seek input from either civilian leadership or industry and did not consult with relevant military logistics planning or support activities. Industrial mobilization planning in the post-1920 period was superficial at best and, therefore, "The muddling that had accompanied World War I mobilization was being repeated."[7] Even as late as 1940, when President Roosevelt wanted some 50,000 aircraft produced per year, there was no guidance as to what types should be produced.[8]

Army/Army Air Forces Logistics Planning

In September 1941, faculty from the Air Corps Tactical School drafted *Air War Plans Division Plan No. 1* (AWPD-1) to address what would be needed should the United States go to war.[9] In August 1942, AWPD-1 was rewritten to address the requirements for conducting an air offensive against Germany, and this resulted in a new plan known as AWPD-42.[10] In the fall of 1942, the US Army Air Force (USAAF) staff made aircraft utilization projections by aircraft type—which included allocations for attrition, transit, reserves, training, and modification—for November 1942 through December 1944, totaling in excess of 65,000 aircraft.[11] However, neither AWPD-1 nor AWPD-42 addressed the needs of the RAF, logistical requirements beyond personnel end-strength, or anything more than a generic total of munitions

required. Operational planning took precedence over logistical planning, which resulted in war plans that were incomplete at best. "The organization and proper position of the logistical arm had long been a subject of debate in the Army and the Army Air Force (AAF)."[12] Recommendations by the commanding general, Army Service Forces (ASF) for standardizing organizations and procedures to improve efficiency and effectiveness were misunderstood and rejected by the War Department. Lack of doctrine resulted in each theater commander establishing complex, unique logistics organizations. Further, the Army's lack of emphasis on logistics training prior to the war—due to outright neglect—resulted in too few personnel with an extensive knowledge of logistics and its functions. Ultimately, during World War II, "Large headquarters with ill-defined and duplicating functions were the rule and achieved only partial success in coordinating supply.…"[13]

In the summer of 1943, the Bradley-Knerr committee made an extensive study of air force installations in Europe and published the *Bradley Plan*, which became part of the *Air Force Buildup Plan*. The plan, largely written by Major General Hugh Knerr, prescribed the manning and organization of air units and installations. A key feature of the plan was the requirement to establish third echelon maintenance activities (subdepots or service groups) manned by Air Service Command (ASC) personnel at each operational base. Third echelon maintenance would be augmented as necessary by depot field teams dispatched from fourth echelon (depot) maintenance organizations (base area depots and advance depots) to take care of abnormal battle damage repair loads. The *Air Force Buildup Plan* provided for coordinated buildup of combat units, increased flow of materiel, expansion of maintenance and supply installations, and increased stateside Air Service Command personnel. Shortly after the *Bradley plan* was adopted, Knerr was selected to command the VIII AFSC in the United Kingdom (UK), where it became his task to put the plan into operation.[14]

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Industrial Mobilization

At the onset of and continuing well into World War II, industrial mobilization was hampered by a proliferation of organizations and procedures.

In 1940, President Roosevelt created an advisory commission to address industrial mobilization. Roosevelt appointed William S. Knudsen, a General Motors executive, as the commission's advisor for industrial production, and the commission reported directly to the President. The commission, however, was largely ineffective.[15] Military efforts to control the mobilization effort and the Army and Navy Munitions Board's autonomy contributed to the commission's difficulties and led to Roosevelt's disenchantment with it.[16] While every effort to gain control of the economy would be thwarted by the President, there can be no doubt this activity behind the scenes created more problems than it solved and negatively influenced civil-military relations. The one bright spot in the commission's performance was giving industry the incentive to build munitions factories by allowing them to amortize all construction costs over a 5-year period. This was the brainchild of

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However, despite all its problems, the OPM accomplished a great deal. It surveyed industry to determine output by examining the potential to standardize production processes.

Donald M. Nelson, the chief merchandizing executive at Sears and an advisor to the committee.

The President replaced the advisory commission with the Office of Production Management (OPM) on 7 January 1941 and appointed Knudsen as its director general, undoubtedly contributing to the OPM's ineffectiveness, as he was not considered a strong leader. The OPM lacked authority and was plagued by organizational design defects resulting in duplication of effort, so it could not dictate to industry, which still preferred to cater to the civilian population. Even Roosevelt's declaration of national emergency on 27 May 1941 did not enhance the OPM's clout. However, despite all its problems, the OPM accomplished a great deal. It surveyed industry to determine output by examining the potential to standardize production processes. In March 1941, it prioritized raw material usage and production of nondefense items. At the same time, the Army and Navy Munitions Board prioritized production of specific defense products. Considering the long lead times required for procuring and manufacturing machine tools, the OPM's identification of a shortage in this area early in the mobilization effort is clearly significant.[17] The OPM also initiated retraining programs to increase the pool of skilled labor and encouraged industry to hire women.

In April 1941, the President created the Office of Price Administration and Civilian Supply. However, when the organization's leader decided to end automobile and major appliance production for the civilian population, a decision with which the President disagreed, Roosevelt moved the civilian supply function to the OPM by creating the Supply Priorities Allocations Board. Donald M. Nelson, appointed to head the board, still worked for Knudsen as part of the OPM but possessed particular authority his boss did not—the authority to set priorities. The board set out to first establish an allocation process and then set priorities within the allocations. In late 1941, industrial production rates were stagnating because of prioritization problems with both raw materials and the mix of consumer-to-defense goods produced as a result of the OPM's general lack of authority. Nelson, in his role as head of the Supply Priorities Allocation Board, cut back on production of automobiles, appliances, and raw material for civil sector use. While the reorganization that created the Supply Priorities Allocations Board did prove to be essential to satisfying the defense requirements for the Victory Plan, the board was often rendered ineffective by government officials who sought assistance from department secretaries or the President whenever things did not go their way.[18] In addition, the board was challenged with coordinating with the Services—who still retained their procurement authority—the Joint Chiefs of Staff, and other powerful organizations.

In January 1942, Roosevelt created the War Production Board (WPB) and appointed Nelson as its chairman. The War Production Board absorbed the OPM, Supply Priorities Allocation Board, and National Defense Advisory Committee. However, these organizations continued to perform a role under the WPB umbrella.

During the war, the advisory committee grew to more than 20,000, with many of these people located at defense manufacturing facilities across the country. Throughout the war, Nelson and his staff were occupied by three problems as they tried to increase production.

- Supplying raw materials from which war materiel and essential civilian products were made
- Providing the plants and equipment in the factories to manufacture the *tools of war*
- Staffing the plants with enough people who had the right skills

Unfortunately, the WPB, like its predecessors, suffered from the lack of real authority to make decisions affecting the civilian populace. Its authority was further diluted when the President created the Office of War Mobilization. It did, however, have "the power to compel acceptance of war orders by any producer in the country and could requisition any property needed for the war effort."[19]

A key example of the effect the proliferation of industrial mobilization organizations and procedures would have on operational logistics is seen in munitions production. Beginning in early 1942, General George C. Marshall headed the Combined Chiefs of Staff, with authority over the munitions allocation process; however, Prime Minister Churchill and President Roosevelt retained the authority to resolve disagreements.[20] The Army and Navy Munitions Board determined military munitions requirements, and the Munitions Assignment Board controlled the assignment of all military hardware. The President and his various civilian organizations controlled resource allocation and the means of production. Clearly, with no fewer than four large organizations involved in munitions planning, the beginnings of major difficulties were created that would hinder the effectiveness of Allied bombing from late 1943 onward.

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In spite of many difficulties, the industrial output of the US grew almost geometrically into 1944. However, demand consistently exceeded production because of "overestimation of capacity by those responsible for producing materiel."[21]

In sum, while the military put much effort into planning, plans were often incomplete because they were formulated in a vacuum. Military leadership did not seek advice from industry leaders or consult with elected officials. The proliferation of civilian, civil-military, and military organizations—often with overlapping functions and lacking authority—resulted in duplication of effort, confusion, and frustration. Further, the military attempted to gain control of the economy, contrary to the desires of the President, adding to the problems. Clearly, all of this was counterproductive and retarded the efforts to build and sustain the logistics support necessary to conduct large air operations like Big Week. Major General O. R. Cook, Deputy Director of Service, Supply and Procurement, summed it up well:

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The USAAF's Air Service Command provided stateside depot, technical, research and development, and acquisition support to the Eighth, while the ASF Service of Supply provided the Eighth with items common to the Army and the USAAF.

> It is, therefore, imperative that advance plans provide for more effective civilian war agencies. Most serious duplications, wasteful methods, and complex procedures existed during World War II, when the organization of these agencies was largely improvised. Their very multiplicity impeded the accomplishment of essential activities.[22]

The Pillars of Support

Several military organizations provided logistical support to the Eighth Air Force and VIII Air Force Service Command in the United Kingdom. The USAAF's Air Service Command provided stateside depot, technical, research and development, and acquisition support to the Eighth, while the ASF Service of Supply (SOS) provided the Eighth with items common to the Army and the USAAF. Although the Eighth and VIII AFSC together had a very large logistics capability and capacity, they depended on the ASC and the ASF for supplies and support and could not have succeeded without their assistance.

On 17 October 1941, the Air Service Command was activated and made responsible for acquisition of weapon systems and provision of fourth echelon (depot level) maintenance support to the warfighting commands.[23] Headquarters USAAF established maintenance policies and procedures, while the Air Service Command issued technical instructions.[24] However, there is evidence that field commanders occasionally issued guidance without ASC coordination.[25] In early 1942, the Air Service Command also became responsible for providing airbases with third echelon (subdepot or intermediate-level) maintenance support.[26] By June 1943, ASC's work force of 50,000 worked day and night to support the war effort.[27] The expansion of ASC's depots and acquisition effort was vital to the Eighth's ability to generate and sustain Big Week raids.

The aviation industry in America had focused on research and development during the interwar years. This focus tended to result in the production of aircraft in small lots, so the ASC acquisition function faced the challenge of trying to convert the industry to a mass production ethos.

> In 1940, when President Roosevelt set a goal of producing 50,000 aircraft per year and funds were appropriated in large amounts, severe acquisition problems developed. Many of the carefully developed procedures relating to advertising and competition had to be set aside simply because of a shortage of time.[28]

Additionally, on 9 April 1942, Congress simplified accounting and contracting by appropriating funds for war materiel directly to the Service departments.[29]

"World War II demonstrated the importance of scientific research in a spectacular manner. Never in the history of warfare were there more rapid and far-reaching scientific and technological developments in weapons."[30] Some of the most significant technological developments were the identification of suitable material and process substitutions to satisfy military requirements. Synthetic rubber is a good example of a substitution that was made in World War II. Much time and effort was required to research and develop suitable substitutes, but they played an important

part in providing the logistical support necessary to sustain combat operations. In hindsight, Cook observed, "A most important logistic lesson is that our safety depends on the continuation of this close collaboration in the development of new instruments of war."[31]

Improvements in supportability were also gained through the combination of engineering expertise and quality maintenance. "By strict adherence to the best standards of inspection and routine maintenance, it was possible to lengthen the time interval between overhauls and thus to increase the force available for operation."[32] As early as July 1941, greatly reduced maintenance and supply demand resulted from lengthening aircraft inspection intervals by 25 percent.[33] The official history maintained:

> During the earlier years of the war … the desperate need for aircraft in most theaters argued so strongly for repair of the crippled or damaged plane that air depot and service groups were strained to provide the special skills, equipment, and materials to meet the demand.[34]

The spare parts shortages that existed through the end of 1942 made this problem more acute, and the difficulty was not overcome until late in the war.[35]

Between 1931 and 1939, the Air Corps had fewer than 2,000 aircraft, and the depots' small capacity was adequate as they overhauled an average of 166 planes and 500 engines annually.[36] USAAF expansion after the summer of 1940 was so rapid the Air Service Command found it almost impossible to meet the steadily growing maintenance demands. The USAAF did not initiate depot expansion plans until late 1940; therefore, by 1941, the depots were wholly inadequate. From January 1942 through January 1944, depot modernization and expansion, along with the addition of eight depots and many subdepots, meant that capacity outstripped the availability of qualified technicians.[37]

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There were just not enough skilled technicians to meet demands, and there was no time to properly train unskilled laborers. The Air Service Command found itself in competition with the more attractive war industry employers in recruiting civilian laborers and generally suffered from a lower priority for civil service personnel fills. A training program for military personnel, which graduated hundreds of thousands of technicians, and special technical training programs for civilian employees recruited to work in stateside depots only partially alleviated the personnel shortage.[38]

The Air Service Command also turned to the private sector for solutions, increasing depot capacity by contracting for training and transport aircraft maintenance and adopting mass production methods to improve productivity.[39] Production line techniques alleviated some problems associated with integrating unskilled labor into depot and flight-line maintenance functions worldwide. A task performed by one mechanic was broken down into several simple steps to quickly make new employees productive. Conveyor belt systems were used to support engine overhaul, repair of parts and accessories, and even some phases of aircraft inspection

How Logistics Made *Big Week* Big: Eighth Air Force Bombing, 20-25 February 1944

The Eighth's performance directly reflected that of the Army Service Forces. General Marshall's reorganization of the War Department as America entered the war had created three separate but equal commands under the Chief of Staff.

and repair.[40] Depot management statistically measured and monitored production to identify areas for improved productivity and often adopted the innovative ideas of technicians for improving tools, equipment, and processes. The combination of special civilian training programs, use of military personnel in depots and contractors to augment depot capacity, and process improvements remedied the depot personnel shortage and improved quality and productivity.[41]

ASC acquisition, engineering, research and development, and depot maintenance activities were beneficial to the Eighth Air Force operations. The improvements made within the Air Service Command improved the Eighth's and VIII AFSC logistical support capabilities to some extent. Whether in the form of a new aircraft, a repaired part, an aircraft modification, or a technical directive to maintainers, ASC performance directly impacted the Eighth's performance.

Similarly, the Eighth's performance directly reflected that of the Army Service Forces. General Marshall's reorganization of the War Department as America entered the war had created three separate but equal commands under the Chief of Staff. The new commands were the Army Ground Forces, USAAF, and the Army Service Forces. In the theater, the SOS commander supported the operational USAAF commanders. However, many commanders felt the Services of Supply infringed upon their responsibilities, and many misunderstandings occurred.

The Army Service Forces established command in the UK in 1943, with headquarters functions split between London and Cheltenham, resulting in inefficiency. "This split in SOS HQ was brought about by the desirability of having SOS planning staffs near the various other planning agencies in London and by the inability of facilities in London to accommodate the entire staff."[42] Communications support was inadequate and travel was time consuming, so the geographical separation caused acute problems.[43]

> …SOS was the "rear area" organization of the theater. Under field service regulations, the rear areas of a theater were organized as a "communications zone," an autonomous theater-within-a-theater. The communications zone commander was responsible to the theater commander for moving supplies and troops from the zone of the interior forward to the combat zone. In this regard, he relieved the theater commander from … rear area activities.… In the European Theater of Operations (ETO), however, there was as yet not a combat zone—the entire theater was essentially a rear area. This geographic coincidence… exacerbated the ambiguities over … logistical roles.[44]

The USAAF maintained its own supply system for things unique to its mission. Therefore, split USAAF supply support responsibilities existed as supply support of common items was provided by the ASF Services of Supply. This split was a source of great contention.[45]

Knerr, commanding general of the VIII Air Force Service Command and later the United States Strategic Air Force (USSTAF) Deputy for Administration, was responsible for all USAAF logistics in the United Kingdom. He hotly contested the Army's tables of organization and tables of equipment that placed artificial limits

on authorized manpower and equipment. Knerr wrote in 1945, "The tables of organization and tables of equipment are a convenient and simple means for a staff agency in the United States to do its job easily, but they place the people in the theater of war in a straight jacket."[46] He provided many examples of the impact strict adherence to these tables had on the war. Problems included shortages of vehicles to move ammunition, vehicle maintenance and ordnance equipment, and high-explosive bombs due to increased usage during late 1943. These problems made the execution of Big Week more challenging for the Eighth's logisticians. More important, the latter problem meant that not every bomb dropped would produce the desired effect, increasing requirements to revisit targets.[47] Knerr believed the Army should reinvent its manpower and equipment authorization policies. He wanted the Army to use authorization tables more flexibly, like the USAAF supply tables, treated more as guidelines than strict policy.[48] Although Knerr tried to resolve many of these problems before February 1944, the Army did not adopt his suggestions.

ASC and ASF Services of Supply support was critical to the Eighth and VIII AFSC, but the theater logistics organization evolved throughout the war and was characterized by functional overlaps and power struggles. Even after the VIII AFSC shouldered the responsibility for supply distribution, the Army Service Forces provided it some supply support.

ASC and ASF Services of Supply support was critical to the Eighth and VIII AFSC, but the theater logistics organization evolved throughout the war and was characterized by functional overlaps and power struggles.

Eighth Air Force Logistics

> *Let us, the next time, have our logistics prepared before we plan to operate. We managed to skin by, in this last war, particularly in training personnel, on the logistic side by pulling ourselves out by our bootstraps…. Here 273 groups were set up but not a Depot Group was thought of. That meant that the very late start that was made had to be taken care of in the theater, and in the European theater our logistic establishment in the Burgenwood (sic) area was simultaneously a training school and the support for the operating pilot. But that is a bad situation to be in.*[49]
>
> **—Major General Hugh J. Knerr, USAAF**

An enormous effort was required to receive, support, and sustain the US bomber units, and British support was the key to success in massing strategic bombardment forces within striking distance of Germany. The British provided the materials for and constructed 91 of the 138 airfields required for American flying operations, allowing the forward deployment of USAAF units.

> The buildup of American air and ground forces in Britain (Operation Bolero) was determined by the logistics constraints the British-American coalition faced before the Normandy invasion. During the first year or so of its operational status from August 1942, Eighth Air Force's buildup was greatly helped by Britain's industrialization and the RAF's maturity.[50]

How Logistics Made *Big Week* Big: Eighth Air Force Bombing, 20-25 February 1944

Air service groups provided intermediate-level maintenance support for two combat groups, possibly with the squadrons dispersed. One air depot group supported two air service groups. However, in Europe, an entire combat group, sometimes two groups, usually operated at a single airfield, complicating intermediate-level maintenance operations.

However, logistical sustainment of the deployed units was also critical in order to increase pressure on Germany and step up those efforts during Big Week. These efforts could only be made if flyable airframes and the right munitions were available. Unfortunately, the emphasis at home on aircraft acquisition overshadowed problems of supply and maintenance, which received inadequate attention from USAAF senior leadership until they became acute.[51]

As evidenced by the data in Table 1, the in-theater logisticians found a way to conquer obstacles and get the kind of results necessary to support an effort with the magnitude of Big Week. Although some of the success is attributable to the improvements made stateside, most of the credit goes to the American and British logisticians in the UK and those braving the Atlantic sea lines of communications. Dramatic improvements across the spectrum of logistics were made in less than 1 year, enabling the Eighth to sustain crippling bombing missions against Nazi Germany from Big Week onward.

Leadership and Organizational Evolution

The USAAF established the VIII AFSC to provide the Eighth's combat units with supply, intermediate- and depot-level maintenance, and transportation support. However, in many respects, the AFSC concept was in direct conflict with the ASF Services of Supply.[53]

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VIII AFSC established two depots in England and one at Langford Lodge, Ireland.[55] A government contracting oversight gave Lockheed control of all personnel working at the depot in Ireland, which further complicated operations.[56]

General Knerr spearheaded the logistics efforts within the Eighth up to and beyond Big Week. His past experiences in corporate America, combined with those gained while part of the Bradley-Knerr Committee, did much to influence the logistics organizations and processes supporting the Eighth flying operations. Knerr arrived in Britain in July 1943 as the deputy commander, VIII AFSC.[57] AFSC was separate from the Eighth and subordinated to the numbered air force A-4 (logistics) staff, resulting in conflicts between staff office and operating agency. Knerr pressed for a reorganization of the Eighth, consistent with the recommendation he made to the Bradley Committee, elevating AFSC to a status equivalent to other staff functions. He also sought to consolidate A-4 and AFSC headquarters and reorganize Headquarters Eighth Air Force around two deputies—one for operations and one for logistics. Knerr believed a commander in constant contact with his two deputies could eliminate the need for much staff work and get results by being able to make major decisions quickly. Knerr took control of the Eighth A-4 staff on 11 October 1943, while still acting as deputy commander of VIII AFSC. Shortly after that, he

took command of the AFSC. Knerr, by December 1943, "absorbed the personnel and functions of A-4 to become, in effect, the sole logistical agency entitled to act in the name of the commanding general, Eighth Air Force."[58]

Unfortunately, the Eighth took staff and other resources from VIII AFSC, without warning, to stand up the Twelfth Air Force in October 1943. This unforeseen loss of resources degraded VIII AFSC capabilities for some time.[59] VIII AFSC anticipated the activation of IX AFSC, so when this occurred, it did not affect VIII AFSC as the need to support the Twelfth had.[60]

Reestablishment of the Ninth Air Force in Britain prompted further organizational changes. In late December 1943, General Carl Spaatz, commander of the newly created US Strategic Air Force, established a two-deputate structure, administration and operations. The deputy for administration would direct the logistics efforts of the Eighth and Ninth, while the deputy for operations would direct the strategic operation of both the Eighth and the Fifteenth.[61] With the birth of the USSTAF organization, Knerr became the deputy for administration. Knerr stated, "We had a good demonstration of the smooth operation of that partnership thesis during this war in Europe, and we should never forget that lesson because it produced results."[62] Under this new command structure, Knerr made the final preparations and executed support of the Eighth bombing operations during Big Week.

Workloads resulting from initial combat operations, however, were greater than anticipated. In April 1943, VIII AFSC modeled itself after the Air Service Command by establishing three operating divisions—supply, maintenance, and personnel. This organizational change replaced the traditional general staff structure and produced a more effective operation. AFSC also decentralized operations in conjunction with this reorganization, allowing headquarters to focus on management and process improvement. In 1943, logistics organizations and processes were specialized and optimized, and the reduced threat of bombardment in the UK allowed for more efficient centrally located functions. However, VIII AFSC sustainment of the Eighth's combat operations became a major problem, and the "anxious examination of the factors affecting the rate of bombing operation in the

Activity	Dec 42	Nov 43
Aircraft Assembled	12	463
Engines Overhauled	35	714
Aircraft Modified	5	619
Tons of Bombs Delivered	2,329	18,000
Propellers Repaired	65	375
Supply Tonnage Received	4,000	20,600
Truck Tonnage Hauled	2,700	22,194

Table 1. VIII Air Force Service Command Production Comparison[52]

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How Logistics Made *Big Week* Big: Eighth Air Force Bombing, 20-25 February 1944

Although the number of USAAF personnel in Britain increased by 300 percent in 1943, buildup of AFSC personnel lagged behind that of combat forces and handicapped logistics.

fall of 1943 had emphasized anew the basic importance of its varied functions."[63] VIII AFSC had not addressed all the organizational overlaps, inefficiencies, and difficulties. Despite great organizational improvement, its effectiveness suffered.

Infrastructure, Personnel, and Training

"Britain contained a core of civilian workers with maintenance and supply management skills" but "logistics met with an immediate shortage of British labor at ports and construction sites."[64] Although the number of USAAF personnel in Britain increased by 300 percent in 1943, buildup of AFSC personnel lagged behind that of combat forces and handicapped logistics.[65] Despite the fact that 1,000 Eighth Air Force personnel completed technical schools each month in 1943, Knerr noted the biggest problem he faced in 1943 was a shortage of personnel, and those he did have required training. He solved the problem, at least for the maintenance function, by cycling personnel through the air depot groups for formal training. Once trained, they were reassigned to air service groups, and "maintenance was no longer a problem."[66]

In late 1943 and early 1944, thousands of unskilled and untrained workers were shipped to the UK to help man rapidly expanding depots. In order to use new personnel quickly, production-line methods were instituted. Although this approach was not efficient, there was no other way to productively employ these people more rapidly.[67]

In June 1941, a factory representative section was established in London, and when the VIII AFSC was activated, it became responsible for the section. The factory representatives assisted the RAF and the USAAF with technical problems in the field and at depot. By May, it had 222 civilians representing 34 different American manufacturing companies. Then, as now, the factory representatives were invaluable in sustaining operations.[68]

Supply

"The decision in 1939 … to put almost all of the funds made available to the Air Corps into complete aircraft explains in large part the critical shortage of spare parts which persisted through 1942."[69] Throughout 1942, aircraft grounded for lack of parts was a concern throughout the USAAF.[70] To make matters even more stressful for VIII AFSC, on 1 December 1942, the unanticipated withdrawal of supplies and essential personnel to support the Twelfth created much chaos.[71]

Through most of 1943, the Eighth's logistics system suffered shortages because of shipping losses and the support it provided to the Twelfth. "Shortages of spare parts for such items as superchargers, bombsights, and trucks (which themselves were in short supply) were frequent."[72] However, by the beginning of 1944, more than 190,000 supply items were cataloged, spares were at satisfactory levels, and "no aircraft was long on the ground for lack of spare parts."[73] The improvement is attributable to the synergistic effects of:

- Decreases in shipping losses
- Redeployment of Ninth Air Force to Britain
- Local purchase and manufacture
- Improved transportation, maintenance, and supply distribution processes
- The learning curve
- ASC service life extension and economic repair policies

US forces in the UK relied on merchant shipping that was subject to German U-boat attacks. U-boats caused the loss of 6.3 million tons of cargo in 1942, but losses steadily declined in 1943 and afterwards. Cargo reaching the UK increased from some 50,000 tons in May 1943 to about 1 million tons in December 1943, while monthly losses decreased from more than 700,000 tons in November 1942 to approximately 100,000 tons in June 1943.[74]

Although cargo losses subsided, problems with manifests and cargo markings often delayed deliveries to units. In 1942, ships commonly arrived in the UK without the SOS having received a copy of the manifest or loading information. Even when documentation was received in a timely manner, it was often too general, making planning almost impossible.[75] Actions were taken to standardize markings and documentation, and dramatic improvement was realized.

> As late as the first quarter of 1943, only 46 percent of the manifests and Bills of Lading were being received five or more days before the arrival of the ships, and 24 percent were not received at all. However, during the month of April 1943, 80 percent were received five or more days ahead of ships, and in May 90 percent. Thereafter, delays in receiving documentation ceased to be a serious problem.[76]

SOS unfamiliarity with USAAF markings and procedures delayed distribution of supplies and prompted VIII AFSC to establish intransit depots at sea and aerial ports. Further improvements in distribution were realized by dividing the British Isles into two geographic zones. Northern Ireland was later established as a third zone. Intransit depot zoning was based on the capacity of the geographic area to receive supplies, and ships in the United States were then loaded with supplies based on zones, reducing the amount of intratheater transportation required within the UK.[77]

Consequently, VIII AFSC distributed all USAAF supplies received in the UK. With respect to the Eighth, the Services of Supply provided wholesale supply support, and VIII AFSC provided retail supply support.[78] On 14 December 1943, VIII AFSC reported that intransit depots could deliver bulk supplies from the port to a depot or base within 72 hours. They also reported that 88.5 percent of requisitions were satisfied immediately and requisitions for items not on hand were being filled in less than 24 hours. These process improvements may seem simple, but they did wonders to make the flow of USAAF supplies to and within the UK more efficient and reliable.[79]

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How Logistics Made *Big Week* Big: Eighth Air Force Bombing, 20-25 February 1944

It took the USAAF nearly 2 years to develop an effective supply statistics system to aid in spare parts requirement forecasting. As early as 1942, supply planning was accomplished using automatic supply tables based on peacetime consumption rates for 30-, 60-, 90-, and 180-day stock levels in 20-, 40-, and 80-aircraft units.

It took the USAAF nearly 2 years to develop an effective supply statistics system to aid in spare parts requirement forecasting. As early as 1942, supply planning was accomplished using automatic supply tables based on peacetime consumption rates for 30-, 60-, 90-, and 180-day stock levels in 20-, 40-, and 80-aircraft units. The tables were developed and implemented to help reduce pipeline times for high demand parts with low availability—some were, in fact, taking up to 2 months to obtain from the United States.[80] Supply conferences were held in April and November 1943 to fine tune the tables.[81]

In September 1943, the Air Service Command discontinued automatic resupply shipments for all but new aircraft types. An agreement to ship 50 percent of the 6-month requirement as soon as possible and the remainder 60 days later resolved the problem. Further process refinement averted both shortages and overstocks, and depots were authorized 90-day stock levels of specialized aircraft parts. Subdepots were authorized 6-month levels of common supply items. The prepositioned pipeline stocks were used to fill supply demands at all echelons of maintenance.[82]

In October 1943, the VIII AFSC began to use 3-month forecasts to account for the effects of sortie rates, enemy opposition, repair facilities, and other factors that were not accounted for by the automatic supply tables. Supply transactions were recorded manually, and by late 1943, the aircraft fleet size made it evident that automation was necessary. However, automation did not occur until after 1944. As a result, Big Week did not enjoy the speed and efficiency of an automated supply demand forecasting process. [83]

The amount of equipment being shipped to support the Twelfth caused acute equipment shortages in the Eighth, hampering beddown and support of new units arriving in theater.

> During the early part of 1943, the movement of air echelons to the United Kingdom prior to the movement of ground echelons, service units, and their equipment, contributed to low serviceability. A new unit, for example, seldom reached a serviceability rate higher than 50 percent during the first month of operations.[84]

To alleviate theater shortages, the USAAF began to require units deploying to the UK to ship their own equipment 1 month before deployment.[85] Given the lead times associated with the manufacture of peculiar support equipment items, this policy maximized the number of combat ready aircraft during Big Week.

Before February 1943, all requisitions were passed through HQ VIII AFSC, slowing the process and making it inefficient. After February 1943, the supply channels for Air Force-unique supply items were decentralized. Only those needs that could not be satisfied by military supply within the theater were passed to HQ VIII AFSC and filled, preferably by stateside ASC depots. If ASC could not satisfy the demand, local purchase was used as a last resort.[86] Supply stocks after the winter of 1943-1944 were adequate, and overages were shipped back to the United States.[87] Reinvention of supply demand processing procedures, beginning in February 1943, improved supply support.

In a fine example of cooperation and teamwork, the "British dispensed all the petroleum, oil, and lubricants (POL) in Britain, even though most of it came from the United States under lend-lease."[88] Further, British POL manpower brought some relief to VIII AFSC personnel shortages.

By May 1942, it was apparent that operational requirements would not permit the delays associated with waiting for parts from the United States, so local procurement was begun. The Army SOS established the General Purchasing Board in May 1942 for the purpose of locally procuring goods and services.[89] Shortly thereafter, the SOS commander granted VIII AFSC limited procurement authority.[90] This decentralized procurement tool gave logisticians powers similar to today's International Merchant and Procurement Authorization Card program.[91] Also, by early 1943, local manufacture of some spare parts by European theater of operations depots aided in partially alleviating shortages.[92]

A mutual aid agreement establishing reverse lend-lease with the British was signed 23 February 1942. In the first 2 years of the war, approximately 422,721 tons of supplies were procured from the British.[93] "From June 1942 to July 1943, the British provided US forces in the UK half or more of their quartermaster, engineer, Air Corps, medical, and chemical warfare service supplies."[94] During the war, the United States received more than $6.7B worth of goods and services from the British through reverse lend-lease.[95]

The supply support received from the British was significant as the United States suffered losses of 100,000 to 700,000 tons of shipping per month from late 1942 to mid-1943. Logistics personnel made good use of local purchase, local manufacture, reverse lend-lease, and pooled common supplies. These resources brought relief to weary maintainers by reducing the number of aircraft part cannibalization actions required to satisfy supply shortfalls while maximizing the mission capable rate. The RAF's extensive use of US-built aircraft allowed the RAF and USAAF to create a large pool of common supplies in early 1943. VIII AFSC eventually took over procurement responsibility for the common supply pool, and many items were obtained from UK sources, reducing pipeline time and transport burdens.[96] It would not have been possible to execute Big Week in February 1944 if it had not been for the materials the United States received from the British through local purchase and reverse lend-lease, coupled with the synergistic effect of pooling common aircraft supplies and local manufacture capabilities.

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Maintenance and Munitions

During 1943-1944, the average life of an Eighth Air Force heavy bomber was 215 days, during which it flew missions on 47 days and was undergoing maintenance, repair, or modification on 49 days.

> The quality of maintenance was often the margin of difference between the life or death of an aircrew or the success or failure of a mission. The greatly increased rate of operations, the high incidence of battle damage, and the growing complexity of military planes during World War II made maintenance one of the most vital functions in waging of air war.[97]

How Logistics Made *Big Week* Big: Eighth Air Force Bombing, 20-25 February 1944

Knerr reorganized the VIII AFSC and instituted a system to monitor and control aircraft production. He established statistical reporting and control procedures at all bases so commanders knew what the situation and requirements were.

Maintenance system operations were flexible, and the amount of maintenance was determined by the availability of equipment, supplies, and manpower.[98] Prior to mid-1944, heavy bomber maintenance organizations were constantly challenged by having to expend labor and parts to keep war-weary aircraft flying, since replacement aircraft were not available in sufficient quantities to stabilize aircraft availability with respect to losses.[99] Fighter and medium bomber serviceability was higher than that of heavy bombers "primarily because of a much lower percent of battle damage and less extensive modification requirements."[100] Large theater depots also put increased flexibility into theater maintenance, relieving VIII AFSC organizations on the airbases of a wide variety of labor intensive tasks.[101] In late 1943, General Knerr established subdepots at various operational bases to enhance field maintenance capability. He also implemented a mobile aircraft repair team concept to support onsite repair of aircraft too badly damaged to fly to the depot. In existence between 1943 and 1945, mobile repair teams comprised of supply and repair trucks and specially trained personnel were very important to base maintenance activities. Because the mobile repair teams repaired damaged aircraft that landed off station and aircraft damaged beyond the bases' maintenance capabilities, base maintainers could concentrate on minor repairs and aircraft regeneration.[102]

Further, Knerr reorganized the VIII AFSC and instituted a system to monitor and control aircraft production. He established "statistical reporting and control procedures at all bases" so commanders knew what the situation and requirements were.[103] This included, beginning in September 1943, collecting 3-month sortie forecasts from the combat commands to forecast and adjust depot workloads in order to reduce backlogs.[104] Late in 1942, the British agreed to let Americans replace British workers at the Burtonwood depot, and "under American leadership and production methods the production of engines and instruments increased at a rapid rate."[105] Depot capacity was also increased when Warton Air Depot was activated in September 1943. Several smaller subdepots, known as advance depots, were activated at selected operational airbases to further enhance field capabilities.[106] Knerr's reallocation of repair and modification work in December 1943 took advantage of the efficiency of specialization by spreading backlogs and making the depot in Ireland responsible for aircraft modification kits.[107] The necessity of modifying all incoming aircraft frequently reduced theater aircraft serviceability rates as much as 16 percent.[108] "Following this reorganization, the volume of work accomplished was vastly increased."[109]

Lockheed Corporation, under US contract, manned the Irish depot. Lockheed's depot support was considered advantageous because it provided in-theater specialized engineering work, modifications, development of special tools, design changes, and kit manufacture for all types of USAAF equipment.[110] Finally, "Between 12 and 20 February 1944 no bombing missions had been flown; hence the backlog of aircraft in repair had been diminished, and an unprecedented number of bombers were available."[111] This period of inactivity was the result of poor weather

conditions that restricted flying operations. Maintainers took advantage of the situation to generate the 1,292 aircraft that were available entering Big Week.[112]

The Eighth had a sufficient tonnage of munitions and quantities of ammunition available to support Big Week. However, disagreement centered on the types of munitions available and the types the flying units needed to destroy the targets assigned. Knerr believed the disagreement was due to improper communication of field requirements to munitions production plants in the states. The shortage of desired bomb types began in December 1943 and was not corrected by 1 April 1945. The lack of proper bomb types to support Big Week, given the bombing accuracy of the B-17 and B-24, degraded mission effectiveness.[113]

Transportation

Knerr attempted to address airlift problems, which he had foreseen, by trying to secure the dedicated airlift he had apparently been promised. In the summer of 1943, he wrote, "Not more than 3 percent of the required airlift has ever been forthcoming in the United States from that promised service."[114] With the exception of inter- and intra-island air service, the Eighth was relieved of airlift functions. These functions had been placed under the Air Transport Command sometime in the summer of 1943. Knerr later wrote in his lessons learned, dated 10 May 1945, that air cargo had been delivered to places where it was "extremely difficult to assemble and process" and that units and equipment were separated from each other, delaying unit mission execution in the theater.[115] A military airline was formed by the Eighth for moving troops and supplies throughout the UK and proved its merit by moving an average of 300 tons of cargo and 2,500 personnel per month in 1943.[116]

The Army Service Forces controlled what was shipped via sea to the UK. Knerr felt the Army Service Forces mismanaged sea shipments, and although it never happened, he believed the Air Force should have been allocated dedicated sealift.[117]

Knerr addressed many key logistical problems in 1943. Not the least of his efforts included resisting the return of the Truck Transport Service to the Service of Supply because "until the Air Forces took over segregation and distribution of their own supplies from shipside (sic) to consuming unit, they starved."[118] A shortage of vehicles added to interservice squabbles over control of the ground transport function. "A truck shortage adversely affected distribution, although it was mitigated by Britain's fine transportation system."[119] In addition, the Eighth's trucks were pooled into a single organization and were effective and efficient in moving supplies from port to base and laterally between bases.[120]

Concerning transportation, the Eighth made the best of a bad situation. It operated an intratheater airlift service but depended on Air Transport Command for intertheater airlift. This combination of intertheater and intratheater support apparently satisfied the Eighth's airlift needs despite its dependence on another command. Despite the sealift problems Knerr believed the ASF created, he never was able to secure dedicated sealift.

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How Logistics Made *Big Week* Big: Eighth Air Force Bombing, 20-25 February 1944

Perhaps the most significant lesson of World War II is that the military potential of a nation is directly proportional to the nation's logistic potential.

Eighth Air Force Logistics—The Bottom Line

World War II, as exemplified by the Eighth's tremendous efforts up to and through Big Week, "dramatized as never before the importance of the essentially undramatic functions of transportation, supply, and maintenance and lent new strength to calls for centralization of responsibility."[121] From 1942 right on through Big Week, improvements were constantly sought in all logistical functions to make them more responsive and effective. Many of the accomplishments were achieved because of Knerr's leadership. Although logistics organizations and process deficiencies still existed in late February 1944, many problems had already been addressed and yielded the logistics capability to initiate and sustain operations the size of Big Week. The improvements made within all the logistical functions, combined with continuous process improvements, put the *big* into Big Week.

Success Reaped the Hard Way

> *Perhaps the most significant lesson of World War II is that the military potential of a nation is directly proportional to the nation's logistic potential. The first hard fact to be faced in applying that lesson is that our resources are limited. The next is that the slightest delay or inefficiency in harnessing our logistic resources may cost us victory.*[122]
>
> **—Major General O. R. Cook, USA**

Logistics indeed made Big Week *big* with respect to the Eighth's bombing operations. The Eighth generated 3,880 bomber sorties that delivered 8,231 tons of bombs to targets throughout the Third Reich. The number of operational bombers declined to about 900. However, within 5 days after Big Week ended, maintainers had returned about 150 of the approximately 200 bombers with battle damage back to a combat ready condition.[123] Big Week was *big* because, although Allied air superiority was not won until later, as General Spaatz noted, it did spell the beginning of the end for the Luftwaffe daylight fighter force.[124]

Leadership greatly influenced the logistics capability and support the USAAF was able to establish in the UK. On the negative side, it took a long time for the civil-military organization to evolve into an effective one, and it appears the military spent more time trying to take charge of the economy than to work within the President's system.

General Cook remarked:

> Time is the most precious element in logistics preparation for military security. Measures must be prepared in advance for the all-out, logistic mobilization that must be completed between the time when the danger threatens and the time that war actually strikes.[125]

Indeed, the military did not adequately plan for industrial mobilization, which contributed to the myriad of problems encountered.

Congress' streamlining of acquisition procedures and granting of obligating authority to the armed services greatly reduced lead times associated with the major

procurements necessary to prepare for and prosecute the war. However, military management of acquisitions was not perfect. In 1942, there was an imbalance between the number of whole aircraft procured and the spare parts required, resulting in a parts shortage. Fortunately, the spare parts situation improved by 1943, and maintainers had the spares needed to support Big Week.

ASC research and development activities enabled technologies to be exploited and, thus, improved combat capability through a controlled aircraft modification program. Technology insertion was a positive influence on logistics.

Functional overlaps, process inefficiencies, and what could be labeled *intraservice rivalry* between the VIII AFSC and AFS Services of Supply caused many of the processes critical to providing and sustaining aircraft maintenance to break down. VIII AFSC addressed most of the problems during 1942 and 1943, but Knerr, because of his overall dissatisfaction with ASF support, made every effort to make the Eighth as logistically independent from the Army as he could, and he got results.[126]

VIII AFSC suffered personnel and training shortages. The leadership's adoption of production-line maintenance processes was not the most efficient use of personnel, but it did allow for speedy incorporation of unskilled workers into the depots and service groups.

"Host nation support, or whatever resources happen to be in the place one fights, can contribute greatly to a logistics system's capability."[127] British airfield construction allowed the United States to mass bomber units on the island. Interservice supply support was critical to the Eighth's maintenance. Finally, British dispensing of POL made efficient use of manpower, which was important to the undermanned VIII AFSC.

Civilians also provided critical support to the logistics team. Civilians in ASC worked acquisition programs and provided supply and repair support. The Lockheed employees at Langford Lodge depot provided in-theater support in a much more timely manner than would have been possible had they been located in the United States. Factory representatives further enhanced theater maintenance capabilities. In-theater depots, subdepots, and intermediate-level maintenance organizations provided in-depth aircraft repair service independent of stateside organizations. In addition, they developed and provided limited but valuable local manufacture capability, alleviating parts shortages. By the time Big Week arrived, these organizations had evolved and could provide effective logistical support to the combat units, thus enabling sustained bombing raids of 1,000-plus bombers.

Knerr was the single greatest influence on the capabilities and effectiveness of the Eighth's logistics. From the time he served on the Bradley-Knerr Committee to plan the organization and buildup of forces through his tenure as the US Strategic Air Force Deputy of Administration, he constantly improved all logistical functions. His institutionalization of statistical monitoring and requirements forecasting was used effectively to minimize depot backlogs. His implementation of mobile repair

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teams for battle-damaged aircraft helped sustain the bomber fleet. Finally, he championed making the logistics and operations functions equal at the headquarters level, giving logistics the clout needed to ensure their logistics considerations were taken into account and that logistics and operations were synchronized. "Responsiveness and flexible logistics support requires a management system that consciously links operations and logistics."[128] A good example of Knerr's effort to synchronize operations and logistics was his ability to get 3-month sortie forecasts that were used to plan logistical support.

The processes of producing or allocating munitions, or both, were broken because units did not always have the types and quantities of munitions needed to destroy the assigned targets. Big Week was *big*, but it did not pack the punch it had the potential to because of the many munitions substitutions.[129]

Ship escorts, establishment of distribution zones, ship loading based on destination of goods, improved documentation and communication, establishment of intransit depots, VIII AFSC's pooling of trucks for supply distribution, and theater controlled intratheater airlift were very positive influences on operations.

Eighth Air Force logistics prior to Big Week was the story of *brute force* logistics. Knerr's effort to synchronize logistics and operations and provide responsive, effective, and efficient logistics serves as the benchmark for all airmen. At the end of the day, the logisticians conquered many challenges through innovation and adaptation that yielded improved productivity and paved the way for Big Week. Indeed, Big Week would not have been *big* were it not for the dedicated efforts of the logisticians for months and years prior to 20 February 1944.

Notes

1. Maj Gen O. R. Cook, "Lessons of World War II," Lecture to Air War College USAF HRA, K239.7162241-22, 10 Dec 1947, 4.
2. Edward Jablonski, *Airwar*, Garden City, New York, NY: Doubleday and Company, Inc, 1971, 52-53.
3. USSTAF, "Materiel Behind the 'Big Week'," *USAF HRA, 519.04-1*, 20-25 Feb 1944, 4. On 20 February 1944, Eighth Air Force had fighter escort support from both Eighth and Ninth Air Force units, totaling 902 sorties.
4. Stephen L. McFarland and Wesley Phillips Newton, *To Command the Sky,* Washington, DC: Smithsonian Institution Press, 1991, 168-169.
5. Jacob A. Stockfisch, *Linking Logistics and Operations: A Case Study of World War II Air Power,* Santa Monica, CA: RAND, 1991, v.
6. Maj Gen Hugh J. Knerr, "Strategic, Tactical, and Logistical Evaluation of World War II," Lecture to Air War College,USAF HRA, K239.716246-18, 19 Oct 1946, 3.
7. Alan L. Gropman, ed, *The Big "L": American Logistics in World War II*, Washington, DC: National Defense University Press, 1997, 10-15, 94, 98-100. The War Industries Board, established in 1917, was the focal point for the nation's resource and acquisition management. The Board, short-lived, was abolished in the wake of post-World War I acquisition reform that replaced streamlined procedures with peacetime bureaucracy.
8. Gropman, 21.
9. Maj H. Dwight Griffin, et al., *Air Corps Tactical School: The Untold Story,* Washington, DC: US Government Printing Office, 1995, 45.
10. Haywood S. Hansell, Jr, *The Strategic Air War Against Germany and Japan, A Memoir,* Washington, DC: Office of Air Force History, 1986, 62-63. AWPD-1 called for 61,799

aircraft, of which 4,328 were to be based in Britain, and required 2,118,625 Army Air Forces personnel. AWPD-42 included munitions requirements and called for a total of 8,214 aircraft, including a 50 percent reserve, to be based in Britain.

11. "AC/AS Plans: 1942-1945," *USAF HRA, 145.92-18,* 1943.
12. USASF, *Logistics in World War II: Final Report of the Army Service Forces,* Washington, DC: US Government Printing Office, 1947, 247-250.
13. *Ibid*.
14. "Materiel Behind the 'Big Week'*,"* 1-2.
15. Gropman, 9-31.
16. *Ibid*.
17. Gropman, 23-25.
18. Gropman, 25-31.
19. Gropman, 31-35, 38, 55.
20. Gropman, 265-283.
21. Gropman, 31-35, 38, 55.
22. Cook, 7.
23. Lois E. Walker and Shelby E. Wickam, *From Huffman Prairie to the Moon*, Washington, DC: Office of History, 2750th Air Base Wing, Wright-Patterson Air Force Base, Ohio, 1986, 146-147.
24. AAF Historical Office, *"Army Air Forces Historical Studies No. 51: The Maintenance of Army Aircraft in the United States 1939-1945," USAF HRA, 101-51* (1945), 133. In February 1942, improvements in engine construction enabled overhaul schedules to be changed. Only when inspection revealed it was necessary were aircraft reconditioned. In 1943, the *obsoletion* policy requiring the retirement of combat aircraft after 6 to 8 years of service was changed and replacement was not required until "whenever superior equipment was available."
25. Maj Gen Hugh J. Knerr, "Knerr Correspondence," USAF HRA, 519.1613, October, November, December 1943. Although the commanders who did this probably felt operational necessity justified their actions, they increased the complexity of logistics support by creating nonstandard configurations. Their actions negated the advantages of interchangeable parts and lengthened the time it took for VIII Air Force Service Command intermediate and depot maintenance activities to return affected aircraft to service.
26. Wesley Frank Craven and James Lea Cate (ed), *The Army Air Forces in World War II, Vol 6, Men and Planes,* Chicago, IL: The University Press of Chicago, 1955, 391.
27. Walker and Wickam, 145.
28. Gropman, 123.
29. Gropman, 122, 282.
30. Cook, 18.
31 *Ibid*.
32. Craven and Cate, *Vol 6, Men and Planes*, 389-392. "The basic data from which policies and instructions were derived came from reports which flowed in from the depots and stations and from various inspection activities.... Although jurisdiction of ASC did not extend overseas, it was responsible for providing service units, equipment, and supplies for all AAF commands."
33. *Army Air Forces Historical Studies No. 51,* 134-135. The suggested overhaul time for the B-17 increased from 4,000 flying hours or 30 to 60 months of service in 1940 to 8,000 flying hours or 84 months of service in 1944.
34. Craven and Cate, *Vol 6, Men and Planes*, 393.
35. *Ibid*. By 1944, aircraft production allowed replacement of heavily damaged planes by new ones, and battle damage repair became less critical. ASC was then able to establish criteria

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for determining whether or not it was more cost effective to repair or replace badly damaged aircraft, and the job of the depots "became mainly one of modification and overhaul."

36. Craven and Cate, *Vol 6, Men and Planes*, 389.
37. *Army Air Forces Historical Studies No. 51*, 121, 124, 136-139.
38. Craven and Cate, *Vol 6, Men and Planes*, 395. In 1941, there was an urgent need for more and better maintenance, and the quality of maintenance continued to be low during the early months of the war due to a lack of adequately trained engineering officers and civilian mechanics to man the depots. In part, this was caused both by the increased production pressure associated with the parts shortage that existed through 1942 and the fact that ASC was the lowest priority command for personnel fills.
39. Craven and Cate, *Vol 6, Men and Planes*, 391, 395.
40. Craven and Cate, *Vol 6, Men and Planes*, 396.
41. *Army Air Forces Historical Studies No. 51,* 118-122, 127-128, 135. During the period Jan 1942 through Jan 1944, stateside depot maintenance facilities returned approximately 25,000 aircraft and 90,000 engines to service. In 1943 alone, 236,622 aircraft visited the 200-plus subdepots for repair and other work. Finally, an Air Inspector survey conducted in the summer of 1943 attested to the fact that the Eighth Air Force was satisfied with the third and fourth echelon maintenance support it was receiving from ASC.
42. General Board United States Forces, European Theater, *"Logistical Build-Up in the British Isles," USAF HRA, 502.101-128, 9 Jun 1953*, 4.
43. *Ibid*.
44. Gropman, 345.
45. *Logistics in World War II*, 248, 341. Within the ASF, "there was an unnecessary overspecialization in types of service troops, thereby making it difficult to secure maximum flexibility in the utilization of service personnel." Although it was believed units comprised of both USAAF and Army personnel would improve the situation and some experimenting with this type of organization was done, the idea "was not pushed vigorously."
46. Maj Gen Hugh J. Knerr, "Air Force Logistics," *USAF HRA, 519.8086-1*, 10 May 1945, 2.
47. "Air Force Logistics," 6-7
48. "Air Force Logistics," 2.
49. Knerr, "Strategic, Tactical, and Logistical Evaluation of World War II," 4-5.
50. Stockfisch, 18.
51. Craven and Cate, *Vol 6, Men and Planes*, 390.
52. USSTAF, "*Notes for Supply and Maintenance Chapter,"* USAF HRA, 519.057-4, 1942-1945, 10.
53. *Ibid*.
54. Stockfisch, 19. Further complicating an already complicated task, commanders of combat units wanted command of Air Force Service Command intermediate-level maintenance (air service group) activities on their bases. This quickly became the practice, diluting the authority but not the responsibility of the VIII Air Force Service Command commander.
55. Knerr, "Knerr Correspondence."
56. "Notes for Supply and Maintenance Chapter," 6.
57. *Biographical Data, Personnel Index, USAF HRA, 519.293-1*, 1945. Knerr, a graduate of the US Naval Academy, became an Army artillery officer in 1911. He joined the Air Corps near its birth and retired from active duty in 1939 only to be recalled in 1942, having spent the interim years at the Sperry Gyroscope Company "in work that … proved invaluable both to him and to the Military Service."
58. Craven and Cate, *Vol 2, Europe: Torch to Pointblank—August 1942 to December 1943,* 742-743. As a member of the Bradley Committee, in the spring of 1943, Knerr had prepared

a special report on air service in Africa. In the report, he advocated the elimination of the problems caused by the logistics function being subservient to the staff and operations functions by the simple expedient of elevating the agency to the staff level of command.

59. Stockfisch, 18-19.
60. Notes for Supply and Maintenance Chapter, 6-11.
61. Notes for Supply and Maintenance Chapter, 752.
62. Knerr, "Strategic, Tactical, and Logistical Evaluation of World War II," 5.
63. Craven and Cate, *Vol 2, Europe: Torch to Pointblank—August 1942 to December 1943*, 742.
64. Stockfisch, 18, and Gropman, 346.
65. Gropman, 364.
66. USAF Historical Research Agency, "Notes on an Interview with Maj Gen Hugh J. Knerr," USAF HRA, *168.2-12*, 24 Nov 1947, 1-2.
67. Craven and Cate, *Vol 6, Men and Planes*, 395-396.
68. "Civilian Technicians and Representatives," *USAF HRA, 519.8023*, 1941-1945.
69. Craven and Cate, *Vol 6, Men and Planes*, 390.
70. Craven and Cate, *Vol 6, Men and Planes*, 394.
71. Notes for Supply and Maintenance Chapter, 2.
72. Stockfisch, 19. "During early 1943 spare parts for 50-caliber aircraft machine guns became so scarce that the total supply was pooled in a single depot with telephone requests being doled out by special truck delivery."
73. "Materiel Behind the 'Big Week'," 3.
74. Gropman, 347-348, 359, 361-363, and Maj Gen William E. Kepner, "Supply (Congressional Committee)" Kepner Collection, USAF *HRA, 168.6005-84*, 3 Jun 1945, 2.
75. "Logistical Build-Up in the British Isles," USAF HRA, *502.101-128*, 9 Jun 1953, 25-26. "Entries on the manifest such as '1000 boxes of Quartermaster Class I supplies' were not uncommon."
76. *Ibid*.
77. Notes for Supply and Maintenance Chapter, 3, 128.
78. *Ibid*., 3.
79. Knerr, "Knerr Correspondence."
80. Notes for Supply and Maintenance Chapter, 3.
81. "Stock Control in the ETO," USAF HRA, *519.8024-1*, 1945, 1, 8-9.
82. "Stock Control in the ETO," 25, 31.
83. "Stock Control in the ETO," 3-5, 10.
84. Notes for Supply and Maintenance Chapter, 5.
85. Notes for Supply and Maintenance Chapter, 4.
86. "Stock Control in the ETO," 15-16, 19-23, 36-37. Combat group demands not met were first sent to the air service group, then the depot. If neither organization could satisfy the demand, it was then sent to headquarters VIII Air Force Service Command. A three-tier supply priority system was established, in which priority was based on urgency of need. Aircraft grounded for lack of parts were given highest priority, and those requirements were sent via teletype to the air service group. If the air service group could not fill the request, a teletype was sent to the air base depot, and if it still could not be satisfied, a cable was sent to the responsible stateside depot.
87. Notes for Supply and Maintenance Chapter, 5. AOG rates fell from 5 percent in Dec 1942 to 2.3 percent in Nov 1943.
88. Stockfisch, 19.
89. General Board United States Forces, European Theater, *Logistical Build-Up in the British Isles,* 15.

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90. "Stock Control in the ETO," 22-23. Local purchases were limited to 25 pounds sterling ($100), required written approval of the station commander, and could only be done when urgency of need did not permit procurement through the British Equipment Liaison Officers. Station purchase (for example, contracting) officers had standing authority to make purchases not exceeding 5 pounds sterling.
91. Deputy Assistant Secretary of the Air Force (Contracting). *Contracting Toolkit: IMPAC,* 5 Jan 2000 [Online] Available: http://www.safaq.hq.af.mil/contracting/toolkit/impac/.
92. Notes for Supply and Maintenance Chapter, 2.
93. "Stock Control in the ETO," 19. Reverse lend-lease arrangements were used to make routine purchases exceeding 25 pounds sterling and were processed through the commanding general, VIII Air Force Service Command and the RAF Equipment Liaison Officers.
94. Stockfisch, 18.
95. Gropman, 273, 277.
96. Notes for Supply and Maintenance Chapter, 4.
97. Craven and Cate, *Vol. 6, Men and Planes,* 388, 394.
98. Craven and Cate, *Vol 6, Men and Planes,* 389.
99. Stockfisch, 43-44.
100. Notes for Supply and Maintenance Chapter, 4. For example, medium bomber serviceability went from 29 percent in July 1943 to 92 percent in Nov 1943.
101. Craven and Cate, *Vol. 6, Men and Planes*, 391.
102. "Notes for Supply and Maintenance Chapter, 6, 11. Transport of aircraft via truck to depot in the UK was infeasible due to the physical constraints associated with humpback bridges, narrow winding roads with reverse camber, and bridge clearances.
103. "Materiel Behind the 'Big Week'," 2-3.
104. Knerr, "Knerr Correspondence."
105. Notes for Supply and Maintenance Chapter, 6. Although it is not clear from the historical account if VIII Air Force Service Command sought to replace British personnel at Burtonwood depot with Americans because the British were not productive or if the decline in British employee productivity was caused by the agreement, it is clearly documented that productivity increased.
106. *Ibid*.
107. "Materiel Behind the 'Big Week'," 3-4.
108. Notes for Supply and Maintenance Chapter, 5. The shortage of station overhead personnel also necessitated the use of skilled service personnel for overhead functions.
109. "Materiel Behind the 'Big Week'," 4.
110. "Materiel Behind the 'Big Week'," 6. Despite initial USAAF reservations regarding Lockheed's control of depot personnel at Langford Lodge, which occurred due to an error made by the government in writing the contract, it appears the contractor managed the personnel satisfactorily.
111. "Materiel Behind the 'Big Week'," 4.
112. *Ibid*.
113. Maj Gen Hugh J. Knerr, "Letter from USSTAF in Europe Deputy Commanding General, Administration to Commanding General," USAF, HRA 519.8671-3, 1 Apr 1945.
114. Knerr, "Knerr Correspondence."
115. Knerr, "Air Force Logistics," 7.
116. "Notes for Supply and Maintenance Chapter," 12.
117. Knerr, "Air Force Logistics," 7.
118. Knerr, "Knerr Correspondence."

119. Stockfisch, 19.
120. Notes for Supply and Maintenance Chapter, 12.
121. Craven and Cate, *Vol. 2, Europe: Torch to Pointblank—August 1942 to December 1943*, 742.
122. Cook, 6.
123. "Materiel Behind the 'Big Week'," 4.
124. Richard G. Davis, *Carl A. Spaatz and the Air War in Europe,* Washington, DC: US Government Printing Office, 1993, 327.
125. Knerr, "Strategic, Tactical, and Logistical Evaluation of World War II," 7.
126. Knerr, "Air Force Logistics," 1.
127. Stockfisch, 52.
128. *Ibid*.
129. Knerr, "Air Force Logistics," 6-7.

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From First to *Wurst*: The Erosion and Implosion of German Technology in WWII

In the Beginning

At the outset of the German buildup for World War II, the Germans were, arguably, the most technologically advanced nation in the world. Despite the limitations in the Treaty of Versailles, they secretly designed and built some of the most advanced aircraft in the world. From research into all metal aircraft, such as the Junkers Ju 52,[1] to the Messerschmitt Me 262, the world's first jet fighter,[2] the Germans were on the technological front lines. Yet, in a scant 10 years, the German nation ceased to exist. After the war, with its country divided in two, the technological advances were divided among the conquering powers. Indeed, the battles 5 years later between the Mikoyan-Gurevich MiG 15 and the F-86 were more among German engineers than among the nations actually at war.[3] The reasons for the implosion of the German state are manifold, two of which are addressed herein.

From a technological standpoint, many of the German designs and innovations remain valid. They were the true innovators of some of the world's current aircraft. Indeed, the Germans pioneered the use of wind tunnels, jet aircraft, pusher propellers, metal aircraft, and rockets in an attempt to overwhelm their Allied adversaries. Under the guise of Operation Paperclip, many German scientists and engineers were brought to America to work their magic on the American industry. Despite all this talent and its potential, few of the German designs were actually used during the war. Although their relevance is unquestioned, especially in view of current American (and worldwide) aircraft, they were untapped by the German leadership.

The German management system, especially in terms of the technological industry, was a complex and convoluted bureaucratic nightmare. Their system of committees and rings, coupled with a lack of centralized control at the top, served

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Many of the lessons from the German experience with technology and management are applicable today to the US Air Force.

to undermine an economy that was resource-poor, in terms of both monetary and natural resources. This mismanagement, exacerbated by the effects of the Combined Bomber Offensive, transformed the German industry from one of the best to one of the worst, a system ready to implode had it not been helped on by the Allies. Further compounding the situation was the influence of Adolf Hitler. A man with a continental worldview and a penchant for doing things his way, Hitler was more of a hindrance to industry than a help. His constantly changing requirements led to costly and lengthy delays to the production of many aircraft. His inability to look beyond continental Europe from a practical standpoint ensured the German state never had a practical long-range bomber until it was too late. Indeed, the Germans ended the war with the same fighter and bomber with which they began the war, with only minor modifications and a dwindling ability to mass-produce them.

Many of the lessons from the German experience with technology and management are applicable today to the US Air Force. Without a doubt, today, the United States is the technological superpower of the world, yet it is plagued by many of the same problems that the Germans faced. Many of America's technological advances seem to be done for the sake of technology, rather than for an operational military need. Indeed, many of the needs of the American military may be met, in the short term, with existing technology or modifications thereto, rather than new programs. The true transformation of the American military and its technology will be a departure from the stovepipes of military acquisition, in which each Service acquires its own (often redundant) systems, to a process of standardization among the equipment used to meet each Service's needs. Furthermore, American military management is becoming as complex as that of the Germans. True, Americans have much more to worry about than the Germans; for example the whole, poorly understood realm of space. The United States tends to solve its lack of understanding with additional bureaucracy, which exacerbates the overall situation. Alignment under a specific, overarching unified command could eliminate some of the waste and ensure an interoperable, standardized force for the future. Indeed, if the Department of Defense (DoD) does not learn and heed the lessons of the past, it is doomed to repeat them.

This article examines the efforts and impacts of German technology, both during World War II and today. Furthermore, it examines the impact and folly of German management of the technological industry and that industry's subsequent implosion. Finally, this work draws some parallels between the World War II German system and the current American system, fully recognizing the difference between the totalitarian German state and the democratic American state. Despite the glaring and obvious difference between the two, there are similarities that could have a negative impact on America's ability to wage war.

Technical Marvels

At the outset of World War II, the Luftwaffe was, undoubtedly, the world's supreme air force. It had the most advanced fighter and bomber aircraft and the best trained

crews. Despite this, the Luftwaffe suffered severe losses during the course of the war, including the loss of air superiority over continental Europe, which led to the downfall of the Third Reich. Its loss can be attributed to several factors, not the least of which was its inability to take advantage of, or maintain, the technological superiority enjoyed at the outset of hostilities. The technological superiority was not limited to aircraft fielded during the war but includes some interesting technical innovations that arose during the war but not fielded by the Luftwaffe. Many of these technical innovations are just now being exploited to their fullest potential. Indeed, many of the technological innovations taken for granted today were first developed in the factories and design laboratories of Messerschmitt, Heinkel, Arado, Focke-Wulf, Henschel, and Junkers. These companies—and the designers for whom they are named—were at the forefront of technical innovation during not only their time but also current times. Many of their innovations—such as canards, boundary layer control, sweptwings, variable wings, jet engines, and more—are widely used today and accepted as industry standards. By examining Luftwaffe technological innovations, we can see a clear inspiration and technological marvel that transcends the aircraft industry today and whose impact is just being realized.

Wind Tunnels

One of the most enduring innovations of the Luftwaffe was its pioneering work with wind tunnels.[4] These devices allow an aircraft, or representative model, to be tested under conditions closely simulating those encountered during flight. By using inexpensive scale models of the aircraft, the engineers were able to determine if their design could withstand the rigors of flight across the spectrum of the flight regime. By varying wind velocity, the German engineers were able to simulate high- and low-speed flight regimens. Similarly, by varying wind velocity, they could examine high and low angle-of-attack regimes. By combining the results of these two areas of study, they could determine the robustness and feasibility of the design in relative combat situations. The essential information that arose during these tests was the feasibility of the design, answering several fundamental questions: would the wings remain attached at high speed and high angle of attack; would the aircraft stall at low speed and high angle of attack; what are the impacts of adding externally mounted items to the aircraft; what would happen to the aircraft once an externally mounted device was dropped (would it become unstable, thus unflyable); and what are the impacts on the aircraft center of gravity? These are fundamental questions concerning the flight worthiness of the aircraft that could be ascertained without having to risk the loss of a prototype or pilot.

Additionally, wind tunnels allowed for the testing of new technologies to smooth the flow of air across the wing. The Germans tested boundary area fences, leading-edge flaps, and boundary layer control, all in an effort to affect the flow of air across the wing surface.[5] With the straight, perpendicular wing style of the day, these aerodynamic controls would ensure the flow of air across the top of the wing was as

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To increase range and speed, one of the most enduring German technological innovations was the sweeping of wings.

smooth as possible, thus making the airflow faster and generating more lift. This increase in lift would generate more maneuverability in fighters and more load capability in bombers and more range in both types of aircraft. They tested each of these on many of their experimental designs, but the results of this work only were beginning implementation at the end of the war.

Although the wind tunnels continued to operate throughout the war, their later years' usage was confined to refinement of the V1 and V2 rocket designs. Their staffs were increased in numbers, although those numbers were not used for testing; rather, they were used to mass-produce both weapons. The wind tunnels did stop work during the war after Peenemunde was bombed during the Combined Bomber Offensive, but this was only a brief work stoppage. Once the wind tunnels were relocated to Kochel, they were operational again. Despite this extraordinary testing, the German leadership was determined, by 1944, to focus all efforts on the defense of the Reich. Thus, the tunnels were not utilized to their full potential. The efforts of the personnel assigned to the tunnels were focused solely on one weapon system, not toward testing new technologies or capabilities. This failure to take full advantage of their technological capabilities is a true failure of the German leadership.[6] Indeed, the Germans missed out on several opportunities to exploit fully the wind tunnels, especially in the area of wing design. In this case, the designs were robust and innovative but were not tested by the Germans. Many designs were not tested and developed until long after the war.

The Wings of Man

To increase range and speed, one of the most enduring German technological innovations was the sweeping of wings. During the war, the Germans experimented with a variety of wing sweeps and designs, many of which are prevalent today. Indeed, the most enduring innovation of the Luftwaffe engineers was the rear sweep to a wing, which was found on many of the experimental aircraft designed during the war period.[7] Again, with an eye toward speed and range, the rear sweptwing offers a unique way of increasing lift without increasing weight. By canting the wing aft, the actual lifting area of the wing increased because of the distance the air must flow over the wing. This is done without increasing the surface area of the wing and incurring the corresponding weight penalty, resulting in an aircraft that has greater speed, payload capacity, and range (although all three must be balanced).

The tradeoff with this, however, is limited low-speed maneuverability. The reason here is the specific area where lift is generated. As with all perpendicular and rear sweptwings, the actual lift is generated at the wingtips due to the directioning of the laminar (air) flow over the wings. With perpendicular wings, this lift is approximately abeam the center of gravity on the aircraft, allowing low-speed flight and relatively high angle of attack. With rear sweptwings, the lift is aft the center of gravity, making low-speed flight unstable, thus dangerous. Therefore, by sweeping the wings aft, they were able to gain speed, lift, payload, and range while trading off

low-speed maneuverability. The question the German engineers faced then was how to keep these increases without sacrificing the low-speed regime. Their answer was twofold: increase power (without the weight penalty) and change the sweep of the wings in flight.

One of the earliest proposals, although the Germans never flew it, was a swivel wing. Designed by Blohm and Voss, the idea was to have a single wing that would rotate from perpendicular to canted, depending on mission flight parameters.[8] This aircraft then would be able to take advantage of the low-speed characteristics of a perpendicular wing as well as the high-speed characteristics of a canted wing (less drag, more lift). This concept, although viable, was not proven until the National Aeronautics and Space Administration flew an oblique wing on the Ames AD-1 research aircraft in 1979.[9] Another wing technological approach to overcome the low-speed and high-speed maneuverability tradeoff came through the use of variable sweptwings. Familiar today for application on the F-14 Tomcat, the variable sweep technology is designed to move both wings from a perpendicular configuration at low speed to a rear swept configuration at high speed for the aforementioned reasons. A similar variation yielded the experiments into a solid delta-wing configuration, which consisted of a swept leading edge with a perpendicular aft edge and solid material in between, which yielded some successes but not until long after the war ended.[10]

One of the technological innovations the Germans actually flew in prototype was forward sweptwings. In this instance, Junkers took a conventional wing and swept it forward instead of rear. Coupled with jet engines, this aircraft more than compensated for the low-speed maneuverability liability of rear sweptwing aircraft.[11] By sweeping the wings forward, Junkers changed the lift characteristics of the wing. No longer was lift generated at the wingtips, but with forward sweptwings, lift was generated at the wing root, which was adjacent to the center of gravity. The drawback to this design was the directioning of the wingtip vortices. In rear sweptwing aircraft, the vortices generated by the wind movement across the wing (a spiraling whirlwind) are directed across the wing and behind the aircraft causing little effect to the handling. In the case of the Ju 287, these vortices were now directed along the wing toward the fuselage, making high-speed or high-angle-of-attack flight dangerous. During high speed or high angle of attack, the vortices would overcome the elasticity of the wing, causing the wing to twist off. This difficulty was not overcome until the American X-29 program in the 1980s. Although not currently used, forward sweptwing technology provides a short-term capability, one that is already proven.

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All these experiments into increasing speed, range, lift, and payload were never incorporated into the German production. Many were exploited after the war, however, and remain in use today. Facing an ever-expanding war situation, Hitler issued a series of Fuehrer directives in September 1941 that curtailed work on nonessential projects.[12] Hitler's continental worldview was coming into direct conflict with his strategic expansions. By attacking Britain and later Russia, Hitler

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overtaxed his economic capability to conduct a strategic two-front war.[13] His economic focus switched to producing existing technologies en masse to stem the staggering losses of his overreach. In essence, he sacrificed quality and innovation for quantity.[14] This is prevalent throughout the Germans' technological innovations.

My Grandma Wants to Fly Jets

The second technique available to the Germans for increasing the lift, speed, payload, and range of their aircraft was to couple the rear sweptwings with jet engines. These engines were able to generate much more power than their propeller counterparts and could run on alternate fuels.[15] Although Messerschmitt was the first company to produce a jet aircraft, the first to design and test-fly one was Heinkel.[16] Heinkel actually began his research with the experimental He 178 by coupling jet engines with a perpendicular wing as a planned proposal for a two-engine fighter contract. This never panned out for Heinkel,[17] but Messerschmitt was able to couple the jets with a rear sweptwing design that became the Me 262, the world's first jet fighter. Alas, the Me 262 never entered full production, primarily because of an argument between Hitler and General Adolf Galland over its specific role. Galland argued for the Me 262 to be a pure fighter aircraft, but Hitler was interested in making it a fighter/bomber. This led to a redesign of the Me 262 from fighter to fighter/bomber and back to fighter toward the end of the war.[18] The Me 262 did see some action against Allied bombers, but this was very late in the war, and it did not have much impact on the outcome of the war. Although a successful design, the Me 262 was fraught with powerplant problems. The Jumo 004, the primary jet engine of the time, had a service life of 4-5 hours before it had to be replaced, making the maintenance and logistics of this aircraft cumbersome.[19]

Messerschmitt and Heinkel were not the only ones to experiment with jet engines. Arado had an impact on the US Navy F7U-3 Cutlass of the Korean era.[20] The centrifugal jet engine developed by Focke-Wulf became the primary powerplant for the Yakovlev Yak 15, the first Soviet jet aircraft, used during the Korean war era.[21] Arado also had success with the Ar 234, the first high-altitude, jet-powered reconnaissance airplane.[22] This aircraft was the precursor to the SR-71 Blackbird and the U-2 Dragon Lady. Although these designs had impacts after World War II ended, only the Me 262 was produced in any appreciable quantity by the Germans, and this was late in the war, after the war had been lost.

The Eyes Have It

In addition to out-of-the-box thinking on aircraft design, the Germans were also the first to field and operate an instrument system, both for their own airfields (a precursor to the current instrument landing system [ILS]) and for directing their planes to a target. The first was the Lorenz beam system for blind landing, which consisted of two transmitters located on opposite sides of the airstrip runway. Both transmitted in simplified Morse code, one solely dots, the other solely dashes. The spacing of

the dots and dashes was such that, where beams overlapped, a continuous tone was heard.[23] By moving left and right until the continuous tone was heard, the pilot would be aligned directly on the airstrip center line. Thus, in conditions of restricted visibility, the pilots could find their airfield. The limitations of the system were many. It did not take into account crosswinds or turbulence.[24] However, as pilots became skilled in the operation of this system, they could compensate for these difficulties and keep the continuous tone.

The other disadvantage to this was the lack of altitude information. The beams would guide a pilot to the airstrip, but in conditions of zero visibility, they did not provide altitude. This can be overcome by the directioning ability of the transmitters. Essentially, the overlap portion of the beams (the area with the continuous tone) was conical. As the pilot flew toward the airfield, the cone narrowed toward the centerline. Thus, the absence of a tone could indicate the pilot was too high, and he could compensate accordingly. All in all, it is a risky system, but it is better than nothing. Without this, the pilots would have to divert to another airstrip, one not weathered in, which further added to the distance they needed to fly. This became a significant factor during the Battle of Britain when the German fighter escorts were flying at their maximum radii. Any additional flight time or distance could prove disastrous.

The offensive adaptation of the Lorenz system was known as the *Knickebein* system. Designed to be a long-distance target designator for use during night bombing, the Knickebein system consisted of two Lorenz transmitters, one that looked at the target along the ingress line, the other at the target from the profile. The pilots, using the Lorenz system in reverse, would fly away from the first transmitter while maintaining the steady tone in their headphones. Once they were in range of the target, they would switch to the frequency of the second transmitter, while occasionally checking with the first transmitter to ensure they were still on the proper vector. When the second transmitter gave them a steady tone, they were directly over the target and could release.[25] A subsequent refinement of this system, known as the *X-Geraet*, followed the same logic as the Knickebein system, with some refinements. Instead of using the beam intersection to mark their target, the pilots would fly the original beam toward the target. The second transmitter was actually a collection of transmitters, each of which would broadcast on a particular vector. Where each beam of the second transmitter intersected the first beam, the pilots had to hack a certain distance from the target. The *X-Geraet* pilots then would drop flares to literally light the way for the planes that followed.[26]

A further refinement of this technique was the Y-Geraet system, receiver and transmitter combination, where the aircraft will fly a designated vector and periodically retransmit a signal from the ground transmitter. A ground receiver would pick up the retransmitted signal. By calculating the phase shift, the difference in time between the transmitted and received signals, ground controllers had a picture of whether or not the pilot was on vector and could correct their pilots accordingly.[27]

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This type of ground control (although not the *Y-Geraet* style system) is used today by the ground tactical air control squadrons.

The advantages of these systems, despite their drawbacks, are obvious from the German point of view. They had the ability to direct and control their aircraft as well as recover them in less than optimal conditions. These systems also facilitated night bombing, which adds a psychological effect to the physical effect and destruction. From the British point of view, these systems were of import as they were easy to overcome. Radio frequencies operated over long distances are easy to disrupt once the transmit and receive frequencies are known. The Germans kept their systems simple, using dots and dashes on prescribed frequencies, but the British overcame this by inspecting aircraft that had been shot down. The British did not need to know what to listen for once they had the frequency. Using a technique known as meaconing, whereby the British flooded the various German frequencies with extra traffic, the British were able to defeat the Knickebein and *X-Geraet* systems.[28] To overcome the *Y-Geraet* systems, the British merely jammed the frequency.[29] Despite their limited operational life, these systems were the predecessors to the current ILS and radar systems, both of which allowed for night bombing. As the Combined Bomber Offensive demonstrated later in the war, the Allies were able to keep pressure on the German homeland through daylight bombing by American planes and night bombing by British planes. Without radar and ILS, these night bombings would not be possible, providing the Germans with time to reconstitute or continue production without feeling the effects of bombing.

Subsequent Aircraft Technologies

Faced with the challenge of designing aircraft that could outperform their enemies, the German engineers looked at ways to improve the speed, maneuverability, and altitude of the fighter force. The root reason for this work was the theory that to defeat the Allied bomber streams they would have to attack them at their weakest point, which was from above. Thus, they needed aircraft that could fly at extreme altitudes. In addition to their work on jet engines, the Germans looked at ways to improve propeller-driven aircraft. One of the technical solutions to this problem was fielded in their fighter force. They replaced the old radial air-cooled and liquid-cooled engines with a high-compression piston engine. Essentially a sealed, self-contained engine that was not dependent on a bladder of coolant, this engine allowed fighters to perform negative *g* or inverted maneuvers.[30] This gave them a significant maneuvering advantage when engaging enemy formations. Additionally, this engine would increase the performance envelope of the bomber fleet, allowing them to fly farther than they could with the radial engines. Alas, the performance increase in bombers was not enough to have a significant impact on the war, but the impact of the souped-up fighters was felt. The Allies were able to counter this added threat; however, the Germans succeeded, at least initially, in almost equaling the score with their fighters. Additionally, by examining defeated aircraft, the Allies were able to capitalize on German technological advantages.

Another engine modification fielded by the Germans in limited numbers was a relocation of the engine and propeller. Some of the German aircraft that flew as prototypes had pusher-type propellers. Located at the rear of the fuselage, these pusher propellers were more efficient in terms of fuel usage than traditional puller propellers. The Germans were never able to capitalize much on pusher-propeller aircraft during the war because of their management practices, but the pusher propeller is in use today on long-duration aircraft such as the Predator. Although these were significant technological innovations, ones that have endured and are still in use today, the Germans were unable to capitalize on them because of their failure to properly implement modernization and upgrade their aircraft fleet. As indicated earlier, the German industrial capability was stressed to maintain production of existing aircraft to counter the Allied mass of aircraft. This left nothing for development of new technology.

The interwar years saw the rise of Lufthansa as a commercial airline of the Weimar republic. Headed ostensibly by Hugo Junkers, the main workhorse of the Lufthansa commercial fleet was the Ju 52, an all-metal commercial airliner. The Ju 52, pressed into service during the war as both a cargo aircraft (people and materiel) and a limited bomber, had the capability to carry more items than the previous wood and canvas aircraft. To offset the additional weight, Junkers put on a third engine. This venerable aircraft saw service throughout the war, although primarily as a cargo and troop carrier, eclipsed in the bomber role by the He 111 and Ju 88. Nevertheless, most aircraft built during the war were made of metal, thus more robust and survivable than the previous wood and canvas design. The use of metal aircraft also allowed German engineers to examine the possibility of pressurized cabins.[31] During the war, pilots who flew above a certain altitude were required to use oxygen to counteract the effects of altitude. As an aircraft rises in altitude, the oxygen concentration in the ambient air lessens. If an aircraft flies high enough, it can lead to oxygen depravation, causing the pilot and crew to black out. With the advent of pressurized cabins, the aircraft would be able to fly higher without the requisite oxygen aboard. By pressurizing the cabins, the ambient air within the cabin maintains the same oxygen concentration as it would sitting on the ground, negating altitude sickness and oxygen depravation. Although the Germans never fielded this, it is in wide use in all aircraft applications today.

This led to an explosion of new project activity unequalled in the history of aviation, an explosion that was fueled even further in 1944 by the lifting of all patent protection.

Good Ideas, But…

Throughout World War II, the Luftwaffe sought to maintain its technological superiority over the Allied forces by designing capabilities into their aircraft that would allow them to fly higher and faster than the Allied aircraft.[32] This led to an "explosion of new project activity unequalled in the history of aviation, an explosion that was fueled even further in 1944 by the lifting of all patent protection."[33] The German aircraft industry was populated with some of the premier engineers and designers of the time who were able to come up with some truly revolutionary ideas

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Without clear-cut direction, meaning a vision and goal, not micromanagement, any technological advance is doomed to irrelevance. An overall strategy will provide the engineers with the proper vector to direct their abilities and ideas.

for designing and building aircraft. The Germans were the first to design and use jet engine aircraft, metal aircraft, instrument navigation, sweptwing technology, and advanced testing through wind tunnels. Some of their more radical designs, such as the Gotha flying wing concept,[34] would not be realized until many years after World War II. Indeed, many of their innovations were picked up quickly by the Allied forces. Bower astutely notes:

> Since 1945, the genesis of weapons by all four Allies has been dominated by the inheritance of Germany's wartime inventions. Indeed, the Korean War can be viewed, on the technical level, as a trial of strength between two different teams of Germans: those hired by America and those hired by the Soviet Union. The aerial dogfights between the Soviet MiG-15 and the American F-86 Sabres—both designed by German engineers—dispelled for many their doubts about the expediency of plundering Germany's scientific expertise.[35]

Thus, the Germans did not lack grand and effective technological innovation. Yet, they were resoundingly unable to take advantage of this situation and were completely unable to bring these revolutionary concepts into operation. The reasons for this are manifold, but the centermost reason for their inability to exploit their technological superiority lay with the complex, convoluted, and inefficient management system in place in Germany during World War II.

Management for Dummies

One of the most overlooked practices in the business of technological innovation is the impact of management on the overall process. Management of technology is crucial to the successful implementation of revolutionary ideas and processes. Management needs to be not only knowledgeable about the designs and ideas of the engineers but also receptive to them. Management needs to provide a roadmap to what is to be accomplished. Without clear-cut direction, meaning a vision and goal, not micromanagement, any technological advance is doomed to irrelevance. An overall strategy will provide the engineers with the proper vector to direct their abilities and ideas. Furthermore, management needs to provide clear and unambivalent boundaries to the efforts of the engineers to ensure the technological innovations and ideas stay focused and attainable. Finally, the management structure needs to be streamlined and simple to allow ideas to flow not only laterally but also vertically. Binding management to a complex and suffocating bureaucracy will have the same effect on the industry as a whole.

Alas, the Luftwaffe found itself in just such a predicament during the war. It had a complicated and convoluted approval process for the technological advances forwarded, one that was wasteful of not only resources but also time. It had little strategic direction and no boundaries on the effort to advance technology. It also had the wrong people in charge of the various agencies that headed up, collectively, the overall effort. The result was a host of revolutionary innovations that would have all but guaranteed they remained technologically superior but were doomed to be merely paper tigers by the bulging management process and poor leadership.

These paper tigers were exploited by the Allied powers after the war, but the Luftwaffe was unable to take advantage of them. The overall operational result was an air force that ended the war with the same equipment with which it began, quality equipment at the start but obsolete in 1945 when compared with the equipment of the Allies.

Who's in Charge?

At the core of the management of Luftwaffe technology was Hermann Goering. As Hitler's duly appointed head of the Luftwaffe, he was responsible for ensuring the Luftwaffe had the necessary tools to prosecute the war. The Luftwaffe was responsible for determining its own requirements to ensure it could fight. Similarly, the navy and army each had that responsibility. While this is to be expected, what was lacking in Germany overall (and the Luftwaffe, in particular) was centralized control. There was no one agency in charge of military procurement. Indeed, "production was pitifully small. The fault lies clearly with the Technical Office whose lack of initiative cannot be ignored and with the Luftwaffe General Staff … which failed completely to provide the guidance expected of it."[36] Thus, there was no direction, no vectoring of the effort to ensure the proper item was developed. In other words, there was no one in charge.

Further complicating the effort was the process for placing something on contract. The Luftwaffe would award a production contract for an aircraft based solely on its design.[37] This essentially skips the research-and-development portion of modern-day acquisitions, with the Luftwaffe assuming the risk that the design will not work. In many cases, the prototypes developed did not meet expectations (or requirements).[38] Thus, large quantities of resources were spent and expended for something that did not work. This is an incredibly ineffective way to manage a contract. Further increasing the drag on the resources was the number of programmatic changes enacted. With the swift progress of the war and the swifter progress of implementing minor technological changes, the German factories and modernization centers were hard-pressed to keep up.[39]

Finally, to keep the costs from escalating beyond what was already wasted, the Germans enacted price fixing for the industry. Essentially, a contractor could choose one of three pay categories: one which they were not taxed (but had to be a low contract bid), one where they were taxed, and one where they were taxed and some of their costs recouped. The latter only could be chosen with approval from the government.[40] In essence, from a fiscal point of view, German management of the contract process was a shambles. Valuable resources were wasted by betting the design would work, and the designs were changed constantly, costing more resources and further straining an industry that was undermined by fixing prices to the advantage of the government. This poor fiscal policy was further convoluted by the complicated organizational structure of the German industry.

Early German industrial organizational structure was an attempt to maintain centralized control over industry as it attempted to shift to a wartime footing. In

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One of the toughest challenges faced by management in a technological industry is the issue of quantity versus quality. Both are important and must be effectively blended to have a successful program. Unfortunately, for a country whose industry was poorly managed and resource-constrained and faced with an enemy with a seemingly endless supply of high-quality equipment, the natural tendency to fight mass with mass (matching quantities) overrode the necessity to instill some quality in the airplanes produced.

each of the industries of the Third Reich was one person at the head. Directly beneath the head was a main committee, made up of the industry leaders. Ostensibly, the function of this main committee was to evaluate the way each of the companies in the industry did business, select the best from each, and have all factories implement these best practices. Further refining this process, there were special committees under the main committees that dealt with specific parts of the whole. These special committees were also responsible for implementing best practices among their subordinate factories in an effort to increase standardization and efficiency and reduce cost.[41] In theory, this seems to be a sound business practice; however, management by committee (or in this case, by many committees) was not very practical. When combined with poor fiscal guidance and a lack of strategic direction, this system merely complicated the problem.

Furthermore, in 1940, a system of rings was introduced into the industry. These rings were essentially committees but not limited to one industry. These rings were concerned with items and issues that transcended all industry. For example, the ring concerned with the making of steel would have an impact on all committees who used steel (which was all of them). The system that finally evolved consisted of "4 main rings for subcontracting and 8 main committees for the finished product."[42] Each of these committees and rings had subcommittees and subrings to them, further increasing the bulging bureaucracy. Known as Self-Government of Industry, this system could be effective in the hands of a skilled manager like Albert Speer. The armament industry under Speer became more efficient and productive[43] despite the complicated system. However, under managers like Karl-Otto Saur, the opposite happened. Indeed, as Goering stated:

> Saur was a man completely sold on figures. All he wanted was a pat on the shoulder when he managed to increase the number of aircraft from 2,000 to 2,500. Then the Luftwaffe was blamed that we had received so and so many aircraft and where were they.[44]

Unfortunately, for the Luftwaffe, this thinking tended to dominate the war-production effort. The result was a gross number of aircraft (quantity), many of which were unusable or obsolete (quality).

Quantity Versus Quality

One of the toughest challenges faced by management in a technological industry is the issue of quantity versus quality. Both are important and must be effectively blended to have a successful program. Unfortunately, for a country whose industry was poorly managed and resource-constrained and faced with an enemy with a seemingly endless supply of high-quality equipment, the natural tendency to fight mass with mass (matching quantities) overrode the necessity to instill some quality in the airplanes produced.[45] The result was a large number of inferior aircraft that could not have kept pace with the Allies, even if they were numerically similar. In mortal combat, quality is often the divide between success and failure. This was proven by the Tuskegee Airmen flying bomber escort from Italy. Although the

number of P-51s sent to escort a bomber formation did not change drastically, they still escorted more than 200 missions without a single bomber loss. This is attributed to both the skill of these pilots and the quality instilled in the machines they flew. Alas, the Germans did not have the quality in their aircraft to overcome this.

By war's end, the Germans had lost the technological superiority they owned at the beginning. Although this can be directly attributed to their management system, this issue was further exacerbated by their failure to integrate the capabilities of the captured lands effectively. Indeed, rather than capitalizing on the capabilities of the workers in the conquered lands, the Germans merely plundered them and brought their populations into slave labor.[46] They failed to realize and take advantage of what was available to them. The result was a slave workforce that resented its masters. Needless to say, this was another cause of their diminished quality. Finally, as the war progressed, the Germans began conscripting just about any male with a pulse, regardless of his civilian expertise. This led to a lack of skilled workers, without whom quality suffered.[47] This is almost a double tap for quantity over quality—specifically, make the armed forces larger to counter the large force regardless of special (or needed) skills, depriving industry of the skilled workers necessary to instill quality in products sent to the armed forces.

However, equipment was not the only area in which quality suffered. As the war progressed, training for pilots was cut almost in half, primarily because of the need to have replacements for pilots lost in combat. The result was pilots significantly less skilled than earlier groups that entered combat. Poorly trained pilots, flying inferior equipment against a determined enemy on two fronts, is a sure recipe to create an even greater need for replacement pilots. In short, the German economy and industry could not keep up with the demands of a two-front, widely flung war and elected the desperation strategy of throwing everything it had into the fray, regardless of training or expertise. The result is obvious.

Although the complicated nature of industry organization is certainly a contributing factor to the inability of the Germans to exact victory, the lack of management and leadership from the top down definitely compounded the problem exponentially. Without a sound and appropriate strategy or roadmap, anything attempted has the distinct probability of failure. From the beginning, the German strategy focused on Europe and a blitzkrieg style of warfare. As Hitler's aspirations grew (and the war with them), the overall German strategy failed to take these new ideas into account.

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Strategizing

From the beginning, the Nazi party rose to power in Germany under the guise of nationalism. Many Germans were still upset over the limitations imposed by the Treaty of Versailles at the end of World War I, in particular the clause that laid the blame for World War I and the resultant carnage squarely on the Germans. Additionally, the German people were adamant about reclaiming the land annexed

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away from them by the Treaty of Versailles. Undoubtedly, there were also some bad feelings about the French, who were seen as most responsible for the War Guilt clause. Thus, there were some strong feelings of being unfairly and cruelly treated in the aftermath of World War I. This was exacerbated further by the inability of the Weimar Republic to effectively fill the void left by the abdication of the Kaiser. The general disgruntlement of the German people led to a fierce feeling of nationalism and a desire to put someone into power who could actually do something about their situation.

Enter Adolf Hitler, a recognized and decorated World War I veteran who had the charisma and rhetoric to rouse the population. Simply put, he knew what to say and had a forceful enough presence to ensure the people believed him. After his election to chancellor and the death of President Paul von Hindenburg, Hitler combined the two offices into that of Fuehrer and began to attempt to make good on his nationalism pledges. Realizing one of the reasons for the German defeat in World War I was the failure to generate the economy to a war footing, the Third Reich began increasing its economic capability.[48] Ostensibly, this was to continue the nationalistic regaining of indigenous German lands unfairly removed from them. This included the German pushes into Austria; the Sudetenland; Czechoslovakia; and ultimately, Poland. This desire to increase their *lebensraum*, or living space, was risky, however. At any point, the Allied powers (then Britain and France) could respond.

Since many of the battles took place within easy distance of Germany, there was no need to delay the production of aircraft to build and stock spare parts; they would just make another airplane to replace the damaged or destroyed ones.

Hitler was emboldened during the operations prior to Poland by the lack of Allied response to his offensives. He assumed they would continue their policy of appeasement after the Poland campaign, especially after he signed a nonaggression treaty with the Soviet Union. Allied appeasement ended with the invasion of Poland, and both Britain and France declared war on Germany. Hitler was ready for this, however, and ordered his troops into France, occupying, in short order, about two-thirds of France.

From here, things began to go south for the Reich, despite their strong army and technological superiority. Up to this point, every campaign engaged in by the Germans had been a blitzkrieg-style campaign:[49] hit the enemy hard and fast to overcome their defenses and then bring them into the Fatherland. As such, the German economy was geared to this type battle. There was reconstitution time between the battles, giving the economy and industry time to recoup the losses. Germany's continental focus was driving its blitzkrieg strategy, and its economy was geared to this. Thus, it produced high-quality, short- and medium-range fighters and bombers in large quantities to accommodate the blitzkrieg of the enemy. Since many of the battles took place within easy distance of Germany, there was no need to delay the production of aircraft to build and stock spare parts; they would just make another airplane to replace the damaged or destroyed ones.[50] While this worked well at the outset of the war, its significance grew as the German battlespace expanded greatly. Compounding this, pilot training was limited to tactical training only,[51] as there

was no need to think beyond this level. Yet, with the onset of the Battle of Britain, the Germans changed strategy, whether or not they realized it.

Strategy Shift

World War II might have ended differently had Hitler elected to maintain his *lebensraum* policy and restrict his actions to continental Europe. Nevertheless, he attacked Britain, ostensibly to ensure the British stayed out of the war. From a tactical point of view, this was a huge mistake. To attack London, his fighters (upon whom the bombers relied for protection) had to operate at the limits of their range if they were to successfully return to France. In other words, he was now fighting a strategic war with a tactical force. Hitler had arbitrarily escalated things, a precursor of things to come.

As the war progressed, Hitler would return time and again to the concept of changing things to fit his worldview *du jour*, with no apparent thought to the impact on either society or industry. The most glaring example of his inconsistency concerns the Me 262, the world's first jet fighter. Originally designed as a fighter, Hitler ordered it changed to a fighter/bomber against the advice of Erhard Milch and Galland. The resultant delay to retrofit the Me 262 to a fighter/bomber ensured that, when it was ready for use as a bomber, the need was for fighters to defend the dwindling Reich. The Me 262, again at Hitler's insistence, was re-retrofitted back to a fighter, another delay to the program that ensured it was not introduced into the war until early 1945.[52] The argument over the Me 262, in which Goering sided with Milch and Galland, marked the beginning of the end of Goering's favor with Hitler. The result was a complete lack of Luftwaffe representation at future meetings.[53]

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After the loss in the Battle of Britain, Germany took a pause to recoup its losses; then Hitler made another large strategic mistake—he attacked the Soviet Union. Once again, he escalated the war effort to strategic levels with only a tactical industry and military. The results were disastrous for the Reich. They severely overextended themselves on the Eastern Front, which ensured their already fragile logistics support was stretched too thin. Additionally, the demands on industry for a two-front war were too hard to bear. In short, production could not keep up with losses, and there was almost no way to resupply the troops because of a lack of transport aircraft.[54] Finally, the German leadership severely underestimated the Allies' drive and dedication while simultaneously overestimating their own ability.[55] This ill-equipped armed force with little reconstitution ability, fighting a war that was larger than it was prepared for or capable of, with no clear written strategy and numerous changes to the direction of the effort, would have ensured the Reich imploded. However, the Allies were not content to take the time to allow this to happen. They decided to help it on its way through the Combined Bomber Offensive.

Allied Impact on German Strategy

The Combined Bomber Offensive was a massive push by American and British air forces to provide continuous day and night bombardment of the German homeland,

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focusing on its industrial capabilities. The American forces were responsible for the daylight bombing, the British for nighttime bombing. The Combined Bomber Offensive almost stopped before it started, primarily because of a lack of fighter escorts for daylight raids. The massive formations of B-17 aircraft were susceptible to the German fighter aircraft, and the resulting losses almost ended this aspect of the offensive. This changed with the introduction of the P-51, a highly maneuverable and capable fighter with range to escort the bombers all the way to their targets. These fighter escorts also served a second function, that of *attriting* the German fighter force—essentially a trench-style slugfest in the air. It was extremely successful in this second role, removing German air superiority over continental Europe and ensuring Allied planes could roam the European Continent with relative impunity.

The effects on the German industry are even more telling. In addition to other targets, the Allied offensive destroyed the German transportation network, severely limiting its ability to operate a dispersed industry. Furthermore, the Allies concentrated their efforts on the critical Ruhr valley, which was the location of German stocks of coal.[56] The coal was used as a power-producing source and critical to the German war industry. The effects of these raids were felt throughout German society and industry as it placed severe hardship on its already overstressed and limited supply of raw materials and transportation. Compounding the German situation, the Allies struck many of its fuel sources. Indeed, in the after-war interrogations, Goering admitted that fuel was a significant limiting factor to production, especially in the production of a four-engine bomber. In discussing the He 177, Goering said, "I had to ground that aircraft because it consumed too much gasoline, and we just didn't have enough for it."[57] Finally, the Allied attacks had a significant impact on the German industry's depots and production facilities.[58] The Combined Bomber Offensive was more than a combination of American and British bombing techniques. It combined with the Germans' inefficient and poorly managed industry to finally break the back of the German war machine.

The German system of committees and rings with all the subcomponents thereof was an attempt to increase efficiency and reduce cost through standardization of production practices. It actually did not happen that way, as it was a system that could not grow to fit the increased need.

Summing Up

Throughout the war, the German state was unable to take advantage of many of its indigenous capabilities. Beginning with decentralized control of their procurement process and abetted by a complicated and wasteful fiscal policy, the industry simply could not keep up with the demands of the war. Furthermore, its organizational structure was not conducive to change. Its system of committees and rings with all the subcomponents thereof was an attempt to increase efficiency and reduce cost through standardization of production practices. It actually did not happen that way, as it was a system that could not grow to fit the increased need. The Germans effectively proved that management by committee does not work in a wartime situation. Compounding this further were the people they placed in charge. With a few notable exceptions, the men selected to run the industry were party lackeys who had limited experience and know-how when it came to running an industry.

Strategic direction from the state leadership was completely lacking. What began as a continental campaign to reverse the perceived unfairness of the Treaty of Versailles rapidly expanded into a global strategic battle for world dominance, all with an economy that was geared toward a blitzkrieg-style tactical engagement. German industry was never able to recover from this continental focus, dooming the strategic efforts to failure. Furthermore, the personal and direct involvement of Hitler into all aspects of the war effort only served to confuse and befuddle the national leaders. In other words, absolutely no direction was provided to guide the war effort. This led to numerous production delays as aircraft were constantly fitted and refitted to meet the ever-changing requirements. Additionally, the German leadership had two key misconceptions that may have attributed to their constant change. First, they underestimated the Allies, and second, they overestimated themselves. The added impact of the Combined Bomber Offensive served to exacerbate an already deteriorating situation and helped ensure the 1,000-year Reich lasted a mere 12 years.

Forward to the Future

As the US Air Force begins its fourth major transformation in 11 years, there are some striking similarities between what it currently faces and those challenges faced by World War II Germany. Notable among them is a strong sense of nationalism. No one can doubt the surge in American patriotism since the 11 September 2001 events, and one cannot overlook the sense of outrage and frustration at the horrific waste of human life and American potential. Yet, a parallel can be drawn between this and the general feelings of the average German during the interwar period. The Germans felt a sense of outrage and frustration at not only the loss of land but also the humiliation that accompanied the Treaty of Versailles. In hindsight, these feelings perhaps are justified, but the results for Germany were disastrous. Fortunately, the American people are not following the same political trend, nor could we, given our process for electing our officials and the constraints and restraints placed upon them.

As the US Air Force begins its fourth major transformation in 11 years, there are some striking similarities between what it currently faces and those challenges faced by World War II Germany.

Currently, there is no real centralized control over the US Armed Forces acquisition program. As it was for the Germans in 1935, the US Armed Forces currently follow separate stovepipes for acquisition of weapon systems. There are separate DoD programs for ballistic missile defense among the Army, Navy, and Air Force, as well as different programs for acquisition of unmanned aerial vehicles. The acquisition programs for the F-35 Joint Strike Fighter follow the same path, each Service pursuing its own agenda to meet its own needs. This was exactly the same at the beginning of the German buildup for World War II. Each service had its own unique requirements, and each pursued them independently of the other. The result was an egregious waste of valuable and limited resources, both natural resources and dollars. In essence, they ended up paying for essentially the same thing three times. It is the same today with the American military. We have separate

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programs for the X-45 Air Force unmanned combat aerial vehicle and the X-47 Navy unmanned combat aerial vehicle. Both are experimental, and both operate more or less independently of the other. The end result will be two unique systems that meet specific needs without addressing the overall interoperability between systems. While the Germans were not faced with each branch of the service creating its own flying machine, the overall competition between the Services for constrained resources and the inability of the leadership to differentiate, much less prioritize, among the service requirements led to incredible waste and effort.

Similarly, the US Air Force, today, faces much the same challenge as the Luftwaffe, specifically determination of mission and needs. As the Luftwaffe vacillated between a fighter and bomber, the same struggle goes on today in the US Air Force. With the cost of each individual unit escalating rapidly (because of the investment in technology), what is the priority, fighters or bombers, given that the United States really cannot afford both? Further complicating matters is the need to build tankers and lift aircraft. While the Luftwaffe merely ignored this, to its detriment, this remains a central concern for Air Force officials. While not a concern for the Luftwaffe, the American conundrum is compounded by the oft-overlooked integration of space into the battlespace. The items placed in space are extremely expensive and difficult to make, yet, paradoxically, are always there to aid the warfighters. As long as these systems continue to perform, they will be overlooked largely by people who do not understand their mission or importance until it is too late. All these compete for limited resources, those doled out with a medicine dropper by a dubious legislative branch. This merely compounds the larger issue facing the Air Force today, that of identity.

Since 1992, the Air Force has undergone four major transformations. The Air Force has evolved from the Cold War hallmarks of Strategic Air Command, Military Airlift Command, Tactical Air Command, and Air Training Command to the current configuration of Air Combat Command, Air Mobility Command, Air Education and Training Command, Air Force Space Command, and Air Force Materiel Command.

Transformations

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When asked exactly what it is the Air Force does, the answer depends on when the question is asked or what is going on in the world. In other words, there is limited identity within the Air Force about its mission. This is exacerbated by the fact the corporate identity seems to change with each new Chief of Staff. As Goering's Luftwaffe provided little or no unique identity and mission to its members, so the Air Force faces the same dilemma. The result has been a restructuring of the Air Force from one that can fight an outmoded form of war to one that can survive in an outmoded form of peace. American worldview, like that of the German forces during World War II, has remained stagnant. While paying lipservice to a contingency-based, flexible, expeditionary force, the Air Force remains firmly locked in the planning and budgeting of a Cold War, two major-theater-war mentality.

The one issue the Department of Defense has handled well is the creation of the unified commands. Each command is designed to be a warfighter or a functional command with expertise in either a particular area of responsibility or a particular function. There is no overlap in responsibility (except for the functional commands, which operate somewhat autonomously of the geographic commands), yet each of the unified commands manages to share resources and information without regard to which component provided it. In many ways, this mentality needs to transcend the programmatic stovepiping in each of the military branches.

The issue of technology is becoming the forefront of American procurement and acquisition issues. As the Germans did in 1935, America now enjoys a technological superiority over friend and foe alike. At the present, there is no match for American technological know-how and application. Yet, this technology is only as good as its application. As the Germans found out, developing technology just because you can is a poor reason to carry out a government program. While the Germans had some technological innovations, such as jet engines and wind tunnels, many of their technological advances were not realized until after the Reich had vanished. Indeed, developments such as the Gotha P.60 flying wing-style fighter were not adopted until recently with the advent of the B-2 Spirit. The German programs were mismanaged from above almost from the start, including no boundaries on where technology could go. The American problem is more geared to including technology into *simple* problems, simply because it is possible. Many of the acquisition programs undertaken by the Air Force fail to consider the *low technology* or already existing technology approach, often at a large pricetag for a limited capability.

Further complicating the picture is the management of our acquisition programs. In most cases, for a new system, it can take 10-20 years from identification of the problem to fielding a system to defeat or answer the problem. Often, the items fielded are obsolete before they enter production because of changing world needs. Granted, the Department of Defense has not fallen into the pitfall that awaited the Germans; namely, changing existing programs to meet evolving needs. However, the Department of Defense tends to create a new program to handle a problem, which significantly compounds the ability to field forces capable of responding in the

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manner in which they are needed. Each of these programs will compete for existing, limited funds, resulting in a compromise that answers neither the existing problem nor the original problem. Additionally, the acquisition process is bureaucratically robust. Very little can overcome the inertia of the albatross (the bureaucracy) surrounding acquisition programs, and nothing gets through quickly. The Department of Defense has so many layers of management to get through that it becomes almost a self-licking ice cream cone when faced with an immediate and unforeseen threat. In certain rare circumstances, this inertia can be overcome, but these are the exceptions rather than the rule.

Finally, the American worldview is stagnant. As the Germans could not see beyond continental Europe, so the Americans cannot see below the strategic layer. The Germans could not see the forest for the trees, and America cannot see the trees for the forest. America still believes, despite the 11 September attacks, that it cannot be touched by a foe. Americans believe the way to counter potential foes is to apply a strategic, precision, lethal force. This may be true when it is a contest between nations, but in a contest between a nation and a nonstate actor, this meets limited success. Thus, America's worldview and its Armed Forces must be ready for strategic and tactical wars, both conventional and unconventional.

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The real answer lies in establishing a warfighting entity that is impartial with respect to the Services' ability to handle the acquisition and technology programs for the entire Department of Defense. The logical choice is to place the integration of all military needs under the unified command tasked with determining the training and evaluation needs for Joint forces, United States Joint Forces Command. With its overarching view of all the unified commands, it is in the unique position to determine what is necessary to fight and win America's wars, both in terms of manpower and equipment. Furthermore, it should be charged with ensuring the interoperability of these programs to meet service-specific needs with minimal changes. In this time of limited resources and increasing needs, standardization is required without sacrificing individual service-unique needs. Additionally, a streamlining of the acquisition process is required to ensure timely answers to emerging needs. Without these changes, our system becomes almost as cumbersome as the World War II German system, a system that can (and in the case of World War II, Germany, did) implode if left alone long enough.

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German Wonder Weapons: Degraded Production and Effectiveness

Introduction

World War II was the greatest conflagration this planet has ever known. It started as a few hegemonic nations annexing territory for economic reasons, then became an ideological battle between right and wrong, and finally ended in a battle of survival for Germany. Facing the Allies' unconditional surrender demands, the Germans combined fervent ideology, a powerful industrial base, and cutting-edge technology to produce weapons to stave off the Allied tide. The effort was mostly concentrated in developing air weapons, where Germany tried, and ultimately failed, to meet the dual and competing needs of strike and air defense. Germany developed several *wonder weapons* to overcome Allied quantitative superiority. Some of these weapons were obviously flights of fancy, while others served as the basis for many US and Soviet weapon systems in the Cold War. German wonder weapons were a cut above anything the Allies had, yet they were not able to change the tide of war because there were not enough of them on operational status. This fact generates two questions. First, why couldn't the Germans produce and deploy their advanced technology in any effective numbers? Second, if German wonder weapons had reached the front in quantity, would they have made a difference in the war's outcome?

The Wonder Weapons

Germany produced a large number of high-technology weapons during World War II. However, unlike the Allies' atomic bomb, electronic warfare, or Norden bombsight, the Germans were unable to reap benefits from their investment.

The Messerschmitt Me 262 is, along with the V1 and V2, the best known of Germany's wonder weapons. It could fly at more than 540 miles per hour (compared to the P-51's 437 miles per hour); had an operational ceiling of 37,000 feet; and

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packed a punch with its four heavy, fast-firing 30-millimeter MK 108 cannon concentrated in the nose.[1] It was so far advanced beyond other fighters that General Adolf Galland, commander of Luftwaffe fighters, declared on his first flight, "It felt as if an angel was pushing."[2] The technology behind this superb aircraft was the turbojet engine, which produced more power than piston engines and created less drag than a propeller. The amazing performance of the turbojets shocked Allied aircrews when they first saw the Me 262. It could easily outrun escort fighters, allowing Luftwaffe pilots to dictate the terms of combat. This was especially important for overcoming the Allies' quantitative advantage. Once they were in close, they could deliver devastating fire from their cannon and rocket armament; only a few hits could bring down a heavy bomber.[3] The Me 262 clearly made Allied air leaders nervous because it represented the potential for Germany to regain air superiority. However, the aircraft was not without problems.

The turbojets of the 1940s were still in their infant stage and required delicate care from pilots and maintenance personnel alike. Any sudden throttle movements could cause an engine flameout, resulting in deceleration and a lengthy engine restart—not ideal when a pilot was in combat. The high speeds made formation flying difficult, complicating the concentrated attacks essential to breaking up bomber formations.[4] Both these limitations required highly experienced pilots, something Germany would find in short supply late in the war. Additionally, maintaining the Junkers Jumo 004 engine was time-consuming and needed considerable skill, also in short supply. Each engine had a life of about 15 to 25 hours before needing replacement,[5] creating both maintenance and logistics supply headaches. Rarely did an Me 262 geschwader (wing with 60 to 90 aircraft) have more than 16 serviceable aircraft for a mission.[6] Even with these problems, the Me 262 was still a potential *war winner,* if not for production and operational obstacles.

Germany was an early pioneer of air-to-air and air-to-ground rockets and missiles. One of the simplest, yet most effective was the R4M unguided rocket. The Me 262 could carry 24 of these small, simple, easy-to-produce weapons. Their size belied their strength: fired from outside the range of American .50 caliber defensive guns, one R4M had "indescribable efficiency—firing a salvo would hit several bombers—one rocket would kill them."[7] The attacks had the added benefit of breaking up bomber formations, making them more vulnerable to other Luftwaffe fighters. R4Ms also had the same ballistic characteristics as the MK 108 cannon, meaning the Me 262 could use the same sight for both weapons.[8] A more advanced weapon was the X-4, a fin-stabilized, liquid propellant, air-to-air missile, having a speed of 600 miles per hour and a range of 3.7 miles. After firing it from an Me 262 or Focke-Wulf Fw 190, the pilot would guide it to the bomber target via a wire connecting the missile and launching aircraft. Then the missile would detonate on impact or with an acoustic fuze.[9] The guidance system had the major disadvantage that the pilot could not maneuver his airplane while guiding the X-4, a serious problem considering Allied escort fighters. Germany was developing an acoustically guided version,

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using a type of sonar to reach the target and explode, but the war ended before it was ready. Had the Germans deployed the R4M or X-4 in significant numbers, it could have dented the Allied bomber offensive. Moreover, since the Luftwaffe was primarily a striking force, German scientists did not confine themselves to air-to-air missiles.

Germany developed two air-to-ground guided weapons during World War II, both used primarily to stem the tide of Allied shipping crossing the Atlantic Ocean. The first was the Henschel Hs 293—a 1,100-pound bomb with 10-foot wings, a tail, and a liquid rocket engine. The launching aircraft would fire the Hs 293 from outside the target ship's antiaircraft range (possible with the bomb's rocket), then remote control it via radio during its terminal glide to impact. The Hs 293 only impacted at 450 miles per hour, so it had less penetrating power than conventional bombs and was effective only against merchant ships.[10] The Germans overcame the penetration problem with the Fritz X guided bomb. This weapon did not have any propulsion. Rather, the aircraft dropped it as a normal bomb, then the bombardier guided its steep descent by radio remote control.[11] Both the Fritz X and Hs 293 had spectacular success, but Allied defenses overcame these weapons because of limitations cited later. Interestingly, the primary carrier of both weapons was the Heinkel He 177, a bomber whose serviceability greatly limited the bombs' employment, indicating Germany's integration problems.

The Germans also used rockets to propel their fighters. Two specific rocket fighters stand out as examples of what Germany was first able to design, then what shortages drove them to implement. First, the Me 163 was a high-performance interceptor. It relied on its flying wing design and single Walter R II-203 rocket engine to produce astonishing performance. It could reach more than 620 miles per hour and climb to 20,000 feet in a little more than 2 minutes. Allied fighters could not touch it, and it presented bomber gunners with a near impossible leading aim calculation. Like the Me 262, however, its propulsion system was not perfect. The fuels were hard to manufacture, extremely corrosive, and would explode if not properly mixed.[12] Further, two of the fuel tanks were beside the cockpit; any vapor or liquid leaks were life-threatening to the single pilot. The rocket burned more than 18 pounds of fuel per second, giving it not much more than 100 seconds of total burn time before the Me 163 became a vulnerable glider. Therefore, while it was a good basic design, lack of further development made the Me 163 operationally ineffective.

The Germans also used rockets to propel their fighters.

The second German rocket fighter was driven purely by economic and pilot shortages. The Bachem (Ba) 349 Natter launched vertically, climbed at more than 15,000 feet per minute, then flew at 600 miles per hour into the Allied formations, where it released its noseful of unguided rockets. Once its fuel was spent, the Natter glided back to base where the pilot ejected himself and the rocket engine—both then parachuted to earth.[13] The reason for this event was threefold. First, the aircraft structure was cheap and made of noncritical materials, so it could be disposed of. Second, the rocket was difficult to manufacture, so it needed to be saved. German engineers also knew that the shock of landing was likely to detonate any residual

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fuel, with dire results for the engine and pilot. Finally, the Natter was designed for inexperienced aviators. Since the vertical takeoff required no skills and landings were not attempted, pilot training could concentrate on intercepting the enemy.[14] This was clearly an extreme circumstance brought on by Germany's desperate situation late in the war.

The final wonder weapons of note were the V1 and V2 rockets, likely the best known of any German weapons. The V1 or Vergeltungswaffe (vengeance weapon) 1 was the world's first cruise missile. It employed a novel pulse jet engine (which made a distinctive sound, hence the name buzz bomb) and short wings to carry its 1,874-pound warhead to targets up to 150 miles.[15] While the overall idea was advanced, the V1 was actually unguided and flew a straight course until its primitive range-setting device locked the controls and crashed the missile into whatever was below, detonating the V1's warhead. This obviously was not a precision-strike weapon, but it did kill 6,184 people in and around London. This is still a record number of cruise missile deaths, impressive considering the number the United States has launched in the last 13 years.[16] The V2 was a prewar project designed to attack targets beyond the range of artillery. It was an unguided ballistic missile and the forerunner of today's intercontinental ballistic missiles and tactical ballistic missiles (the Scud is a direct descendent). The 28,500-pound missile lifted its 2,200-pound warhead[17] in a ballistic trajectory, then plummeted to earth at more than 2,200 miles per hour.[18] V2s were unstoppable after launch; the only way to halt them was bombing the factories or launch sites. V2s inflicted 2,754 deaths in London, Amsterdam, and Antwerp, a record that stood until the immense Scud exchanges of the Iran-Iraq wars.[19] The V1 and V2 were the only mass-produced and employed wonder weapons. As we will see later, there were several reasons why they were not able to produce the effects Germany needed to turn the tide of war.

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It is evident the Germans developed air weapons without equal. However, their failure to mass-produce and deploy these weapons is a monument to *what could have been*. It is important to remember that while the air effort received the most attention, the Germans also developed land and submarine wonder weapons, all theoretically capable of providing the push Germany needed to overcome the Allies.

Production Problems: Why Germany Could Not Deploy the Wonder Weapons

Germany arose from the ashes of Versailles to become a huge economic power. Its industry, technology, and mass-production capacity led Europe and most of the world in the 1930s. So why could Germany not produce its wonder weapons in significant numbers? The problem was not capability. Rather, it was the restrictions and obstacles Germany placed on its industry that affected the production time line of extremely sensitive weapons. Four reasons behind Germany's lack of production are discussed here: political and military interference; the difficulty of mass producing advanced weapons; a lack of strategic vision; and finally, damage and

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dispersion resulting from the Allies' Combined Bomber Offensive. Any one of the reasons was enough to hamper generating high-technology arms; all four in concert were absolutely crippling.

Political interference was a great obstacle to producing weapon systems and was particularly fatal to advanced systems that required long development times. The political obstruction started early and at the top of the Nazi hierarchy. On 11 February 1940, Hitler canceled all development work that could not get aircraft to the front within 1 year.[20] Work stopped on a half dozen major projects, from jets to long-range bombers, all of which would have made the Luftwaffe more capable of fighting a lengthy war. When Germany became desperate for advanced weapons, its hurried response would produce aircraft that had not benefited from full development processes. So confident in early victory were Germany's leaders that they cut the legs out from under the Luftwaffe before the major war really started, denying it any chance of victory in a drawn-out conflict.

High-level conflicts marked the Nazi regime, as Hitler dueled with his advisors for control of the German military's strategic direction. Hitler cut through many of these disagreements by removing dissenters and consolidating power to himself. For example, he already had taken command of military operations when he took control of critical production programs. Although Hitler had a weak technical knowledge of aviation,[21] he realized the importance of jet engines and personally controlled jet engine allocation after June 1944.[22] His tight control took allocation away from production experts. The result was haphazard distribution to manufacturers and operational units, with a corresponding drop in production and aircraft in-service rates. Compounding Hitler's central control was his top officials' fear of or refusal to confront him on decisions they knew were wrong. At best, dissenters received Hitler's extreme verbal abuse, at worst, removal from office. By 1943, Hitler distrusted the Luftwaffe, and there were many cases of Hermann Goering's passively watching Hitler sow the seeds of his air force's destruction.[23] Even the outspoken Erhard Milch, chief of Luftwaffe production, took orders without objection. When Hitler *uncanceled* the Me 209 program in August 1943, Milch said, "But I have my orders. I am a soldier and must obey them."[24] He knew the restart would split Messerschmitt's production between an obsolescent fighter that would never see operational service (the 209) and a potential war winner (the 262). The best and most damaging example of this phenomenon is seen in the saga to produce the Me 262.

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The Me 262 jet started development as a fighter and had capabilities far beyond contemporary piston engine aircraft. It was the top priority for production after Galland's first flight and subsequent endorsement. Milch canceled the Me 209 program to devote full attention to the new jet. However, Hitler interfered and restarted Me 209 production, largely out of fear of another failed advanced aircraft (such as the He 177) and its associated risk. There were already several problems with getting the Me 262 into production. Milch knew Hitler's decision to continue the Me 209 would take up space on Messerschmitt's assembly lines and delay operational

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High-level interference and bickering were not the only impediments to production. The Luftwaffe's officers contributed as well.

employment of the Me 262 but went along, happy the Me 262 was still a fighter.[25] Unfortunately, Hitler's interference in the program had only started.

Hitler observed Me 262 demonstrations in December 1943 with several staff members, including Goering, Milch, and Galland. After seeing the Me 262, Hitler remarked, "I see the Blitz bomber at last! Of course, none of you thought of that!" Galland, referring to the plane's obvious fighter characteristics, remarked in his autobiography, "Of course, none of us had."[26] Milch actually went behind Hitler's back and continued developing the Me 262 as a fighter. When Hitler found out and confronted him at a meeting on 24 May 1944, Milch responded that the plane required extensive modifications and delays to become a bomber. Hitler exploded. "You don't need any guns. The plane is so fast it doesn't need any armorplate either. You can take it all out!" He then turned to the Luftwaffe's director of research, who responded that Messerschmitt could make the modifications without difficulty (actually, removing the guns and armor to make way for bombs would have changed the center of gravity so much Messerschmitt would have had to move the wings). Goering and Galland were so browbeaten, they remained silent, but Milch finally had enough, saying, "Even an infant could see it was a fighter."[27] Hitler fired him 2 weeks later. Thus, Hitler's meddling and his highest advisors' ineffectiveness at objecting caused significant delays in a potential war-winning aircraft and led to the dismissal of his best aircraft production coordinator. The Me 262 would eventually become a fighter but too late to be produced in numbers sufficient to wrest air superiority from the Allies. There were other systemic problems with producing the jet fighter, but Hitler's interference made it impossible for Messerschmitt to stick with a firm production schedule. This was only one of several obstacles that kept the wonder weapons out of the air.

High-level interference and bickering were not the only impediments to production. The Luftwaffe's officers contributed as well. Galland remembers rival fanatical groups within the officer corps, some more dedicated to Nazi idealism than actually producing an effective air force. This led to a crisis of trust and leadership, two elements on which depends the fighting strength of any unit.[28] Its result was no single voice speaking for the operational and strategic needs of the Luftwaffe; it also made it difficult for the Luftwaffe to present a united front to deflect high-level interference in weapons programs. Furthermore, we often remember the Luftwaffe as an honorable band of eagles. However, several pilots accepted checks from aircraft companies to endorse their products—planes that were often inferior.[29] This, combined with Goering's financial interest in several aviation factories, meant Germany based production choices on personal profit, rather than capabilities. Making inferior planes not only put the Luftwaffe further behind but also took assembly line space away from advanced projects. Military interference also played on a grander scale before the war even started by creating a war industry that could not meet the demands of mass production.

Germany's advanced technology production problems lay both in the character of the industry and pervasive military interference from project inception through

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delivery. First, German industry was craftsman-based to deliver very complicated weapons.[30] This was ideal for creating wonder weapons but made it nearly impossible to mass-produce them. Second, the armaments industry spread its capacity over several different specialized designs. Instead of a core of proven aircraft, German industry had 425 types,[31] once again hindering mass production and limiting the number of advanced aircraft produced. The reason behind this structure was military fastidiousness—the Wehrmacht liked working with specialized craftsmen because they could respond to the field's demands for weapon changes.[32] These changes did make the weapons more effective, but the constantly changing specifications made mass production impossible. No engineers or industrialists were consulted before making changes,[33] creating inefficiencies that further limited production. Finally, the Luftwaffe's first transformation came during the 1930s, when it could upgrade its equipment in peacetime. Conversely, the Allies had to transform early in the war; then stuck with late 1930s technology pushed to its limits, a huge production capacity overcame any qualitative shortfalls. However, Germany tried to transform to wonder weapons late in the war. Transitioning to a superior model in war actually can cause substandard combat readiness and degraded logistics as operators and maintainers learn to deal with new technology.[34] The result was German industry produced too little, too late, and actually decreased the Luftwaffe's capability.

Political obstacles, military interference, and an industry ill-equipped to make advanced weapons combined to hinder the wonder weapons' deployment. The cause of these problems was a complete lack of strategic vision, which prevented effective campaign planning and long-term weapons production. The lack of vision began at the highest levels and set a tone of short-range thinking that permeated the Luftwaffe, ultimately crippling its ability to prosecute any kind of strategic warfare. Goering was an extremely able fighter pilot. During World War I, he took command of Manfred von Richthofen's Jasta when the *Red Baron* died in action. However, Goering never gained the technical and logistical perspective needed to command an entire air force.[35] Before the war, he abandoned the 10-year prewar plan for a well-staffed and exercised strategic air force in order to attain short-term goals quickly.[36] The discarded plan included high-tech weapons, long-range strike aircraft, and the ability to put the German economy on a war basis before hostilities began. Even in early 1941, Goering could have pursued an aggressive program to increase German production but failed to do so. Luftwaffe military leaders also were more interested in active operations than preparing for the long term, because they desired tactical superiority at the expense of strategic readiness. This resulted from the massive catchup game Luftwaffe personnel played between the wars and made the officers technocrats and operations experts with limited vision. They could not relate airpower to national strategy, and the resulting defects were fatal.[37] When losses outstripped production in 1942, the Luftwaffe finally demanded construction increases. By the time the numbers caught up, there were not enough aircrews to fly them.[38] The only vision Germany had was a fanatical desire for a technological breakthrough to turn

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the tide of war,[39] relying on a belief in German superiority rather than reasoned strategic planning. Their fanatical desires not only diverted resources from realistic weapons programs but also gave the Allies targets for the Combined Bomber Offensive—the final impediment to German wonder weapons production.

Any discussion of German weapons manufacturing difficulties is incomplete without considering the Allied bombing campaign. Basically, the Combined Bomber Offensive made an already bad situation untenable for manufacturing wonder weapons. The reader must understand the Combined Bomber Offensive did not stop aircraft production—in fact, more aircraft rolled off the lines in 1944 (39,807) than in any previous year (15,904 in 1942, 24,807 in 1943).[40] However, it caused many operational problems for the Luftwaffe, as we will see in the next section. The Combined Bomber Offensive did cause two major problems with production, negating the impact of increased numbers. First, the bombing forced German industry to disperse, a measure contradictory to mass production.[41] Unlike America's huge aircraft plants like Willow Run, Germany had small factories in many places. While this made Allied targeting more difficult, it also hindered component integration. Different manufacturers also used different tolerances, meaning parts often did not fit together when assembled in the field.[42] Second, as soon as the Allies saw German wonder weapons in action, they were quick to find and strike the factories. After seeing Me 262s successfully attack a US bomber formation at 100 to 1 odds, General James H. Doolittle told Air Marshal Arthur Tedder, "Something must be done, and done quickly."[43] The result was dedicated, systematic attacks on wonder weapon facilities. It is very difficult to mass-produce sensitive, technically advanced weapons with dispersed industry subject to intense bombing. Increased Allied pressure also caused heavy operational losses with which replacements could not keep pace. This attrition was the final explanation for why the Germans could not produce their wonder weapons in significant quantities and turn the war in their favor.

Any discussion of German weapons manufacturing difficulties is incomplete without considering the Allied bombing campaign. Basically, the Combined Bomber Offensive made an already bad situation untenable for manufacturing wonder weapons.

Operational Difficulties: Would the Wonder Weapons Have Made a Difference?

This article has shown the obstacles Germany faced that made wonder weapon mass production and deployment nearly impossible. Even so, it did get limited numbers of its advanced hardware into service. This section will examine whether or not additional weapons would have attained Germany's goals. We must consider both the equipment and other factors such as available crews, training, and the operational constraints imposed by the Luftwaffe's ineptitude and the Allies' air superiority actions.

The first questions we must ask are, were the wonder weapons really that advanced, and if so, were they practical? In many individual cases they were advanced beyond the Allies' equipment, but they were incomplete packages lacking systems integration to other technology. For example, the Me 262 had the devastating 30-millimeter cannon. However, it never reached its full potential because the world's

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best optics industry could not design a good gyro gunsight that would fit in the jet.[44] A few experienced pilots learned to overcome the deficiency, but increasing numbers of rookies could not, leading to poor combat performance of an otherwise devastating weapon system. Further, the advanced Me 163 quickly ran short of fuel, then glided back to base. Similarly, the Me 262 flew slowly in the landing pattern, and its sensitive jets precluded any sudden power increases. US fighter pilots knew this and, thus, overcame the rocket and jet menace by orbiting their airfields, waiting to bounce the vulnerable fighters returning to base. This, in turn, forced the Germans to use Fw 190Ds for combat air patrols over their fields,[45] further exacerbating the fuel shortage. The air-to-ground weapons likewise had their faults. After releasing the Fritz X or Hs 293, the bomber had to fly a predictable course at only 165 miles per hour until bomb impact,[46] making the lightly armed bombers easy prey for naval fighters. Therefore, while the German wonder weapons were sophisticated, the failure to integrate them into total weapon systems presented vulnerabilities easy for the Allies to exploit.

The advanced technology also presented maintenance headaches for Luftwaffe ground crews. The previous section showed how production problems led to limited spares fabrication and parts incompatibility. Additionally, the emphasis on producing great numbers of new aircraft meant manufacturers were unwilling to *waste* production line space on spare parts, including jet engines.[47] The result was lower in-service rates for aircraft, because without spare parts, damaged aircraft were not repaired. Instead, ground crews cannibalized what they needed to keep other planes in service.[48] Cannibalism invariably led to fewer and fewer operational aircraft. The following story shows the effect of these maintenance troubles. Galland visited JG-7 (Kommando Nowotny) to see the Me 262 in action. The wing's leader, 250-kill ace Major Walter Nowotny, wanted a maximum effort to show why the Luftwaffe needed more Me 262s. This maximum effort consisted of 4 planes out of a unit of 80 aircraft; 2 of the 4 subsequently broke before takeoff. US pilots, having overwhelming numbers, then shot down one of the two remaining aircraft when Nowotny's engines malfunctioned during the dogfight.[49] Germany thus had lost one of its best fighter leaders, who was flying the best aircraft of his career but was let down by a system that could not integrate and maintain it.

The advanced technology also presented maintenance headaches for Luftwaffe ground crews.

Resource shortages forced Germany to use lower technology to gain increased performance. Fuel scarcity led Messerschmitt to experiment with simple steam turbine engines that used 65 percent coal and 35 percent petrol to deliver 6,000 horsepower.[50] They used the Me 264 long-range bomber as a test bed but were not able to produce and integrate the efficient engines before the war ended. Junkers also developed the long-range Ju 390 and worked on a refueling version to take Ju 290 bombers across the Atlantic. Even if the rumored Ju 390 flight to within 12 miles of New York is true,[51] this wonder weapon still could not hit America where it hurt—the industrial areas of the upper midwest. The same would hold true had the airplane used the coal and petrol engines. Similarly, the He 162 jet fighter was another step back: its wooden

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The most salient reason the wonder weapons would not have given Germany any advantage was the decreasing skill and experience of Luftwaffe pilots by the time the advanced systems arrived.

construction used noncritical materials and unskilled labor.[52] Hitler Youth were the intended pilots, problematic considering the plane's tricky handling. Hitler considered the aircraft and pilots expendable to stop the Combined Bomber Offensive. Fortunately for the young crews, they never flew in combat. While these wonder weapons allowed Germany to concentrate more materiel and fuel on other projects, they contributed no real capabilities to the Luftwaffe.

The most salient reason the wonder weapons would not have given Germany any advantage was the decreasing skill and experience of Luftwaffe pilots by the time the advanced systems arrived. There were two main reasons for waning crew proficiency. First, many of the best pilots had been killed in action or rendered unfit for duty. Operational losses meant there were few *experten* left in service. In fall 1944 alone, the Luftwaffe lost 12 pilots with 1,146 kills among them.[53] This not only decreased Germany's combat capability but also meant there were few *old hands* left to pass on hard-won knowledge to the new pilots. Most had been flying since 1939-1940 (some even had Spanish Civil War experience), giving them unmatched combat experience. However, the lengthy combat time placed a tremendous physical and psychological stress on them. Indeed, Galland noticed the lack of fighting spirit, even in 1943, when he saw several fighters fire on bombers from too far away to be effective, then leave for home.[54] However, there were some pilots ready to fight, and the limited wonder weapons gave them the spirit to return to duty. When assembling his Me 262 wing, Jagdverband 44, Galland rounded up the most raffish, battle-hardened veterans, several from the pilots rest home. "Many reported without consent or transfer orders. Most had been in action since the first day of the war, and all had been wounded. The Knights Cross, so to speak, was the badge of our unit. Now after a long period of technical and numerical inferiority, they wanted once more to experience the feeling of air superiority. For this, they were ready once more to chance sacrificing their lives."[55] Unfortunately for them, there were far too few pilots and even fewer superior weapons, those being not advanced enough to matter. Germany had again failed those who served her so well.

The second reason for the decreasing pilot skill was the poor state of the replacement program. Starting early in the war, the Luftwaffe's faith in early victory kept it from increasing the front-line force, so there was no pressure to raise training output.[56] When heavy losses set in, there was no reserve from which the Luftwaffe could draw. Later, when it realized it needed replacements quickly, the Luftwaffe lowered training time to only 112 hours, with 84 percent of the time spent in basic aircraft instead of high-performance combat types.[57] This was half the time Allied pilots received. The Luftwaffe also converted bomber crews to fighters, but the 20 hours' training they received was not enough to prepare them for the rigors of outnumbered fighter combat. Hitler even ordered all fighter groups on the Eastern Front to send two of their best pilots to the Reich's defense forces,[58] making the German lack of air superiority in Russia even worse. Finally, the Combined Bomber Offensive created a fuel shortage, leading to training curtailment as early as 1942.[59]

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Lack of fuel decreased instruction flights, further reducing new pilot skill and experience. All the above meant pilots arriving at the front were not skilled enough to handle basic aircraft, much less employ the highly sensitive wonder weapons (Galland relates how even his veteran pilots had trouble lining up for kill shots in the very fast Me 262).[60] This happened at the time Allied pilots were becoming more numerous and better trained as a result of combat veterans rotating home to instruct new pilots. Allied pilots also were becoming more experienced because of lower combat losses and were flying more aircraft of the same caliber as most German fighters. As the Luftwaffe's losses mounted, it closed the advanced schools, then the basic schools, moving the pilots and aircraft to operational units.[61] Replacements stopped just when the wonder weapons were arriving in numbers. Therefore, even with larger numbers of advanced aircraft, the Luftwaffe did not have the crews to fly them, negating their potential effect on the war's outcome.

Several operational reasons kept the wonder weapons, even in greater numbers, from changing the course of the war. Most of these explanations arose from Allied air superiority and the Combined Bomber Offensive's incessant attacks on German industry and transportation. The struggle for air superiority in 1944 made the Luftwaffe commit 82 percent of its manpower and aircraft to defending the Reich.[62] While this estimate seems high, it does reveal how Germany had to retain forces to protect itself. Further, several wonder weapons, such as the Me 163, were point defense weapons. They were effective defenders but were incapable of extending air superiority over Allied territory or protecting the German Army from Allied close air support and interdiction. Lack of air superiority also meant the Luftwaffe could not conduct offensive operations. This left Germany with no route to victory, as the Allies' goal of unconditional surrender meant Germany could not play a defensive waiting game. Last, defending Germany used many weapons that would have been useful for ground defense and offense. For example, the Luftwaffe employed 10,000 88-millimeter guns as antiaircraft artillery; these guns were also the most effective antitank cannons of the war. Moreover, 500,000 people manned the air defense system, depriving Germany of needed ground troops and factory workers.[63] Hence, wonder weapons in sufficient quantity would provide adequate defense but would not have enabled Germany to go on the offensive and push the Allies away from its borders. As it was, Allied close air support and interdiction left Germany no avenue to overcome the numerical superiority of US and British ground forces.

The struggle for air superiority in 1944 made the Luftwaffe commit 82 percent of its manpower and aircraft to defending the Reich.

Allied interdiction and the ground offensive also kept the wonder weapons from making a meaningful contribution. Allied armies overran many of the Luftwaffe's front-line airfields after the D-day invasion, forcing the Germans farther to the rear. Their subsequent operations from unprepared fields caused lower serviceability, so the Luftwaffe could not meet Allied quantitative superiority with higher intensity operations.[64] Relatedly, Ultra intelligence revealed German movement plans and allowed the Allies to attack Luftwaffe ground units en route to their new airbases.[65] This prevented supplies, parts, and mechanics from arriving to service their airplanes.

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Finally, the Allies' dedicated attacks on German transportation, especially the railroads, kept new aircraft components from reaching their assembly points (necessary because of the dispersed factories discussed previously). They also destroyed completed aircraft before they could reach combat units.[66] The wonder weapons were no exception—the Allies knew their value and were intent on killing the airplanes on the ground instead of facing them in the air. Consequently, wonder weapons in greater numbers would not have had the chance to become operational. If they had, they would be starved for gas; lacking pilots; operating from bases with no ground support; and thus, incapable of making a difference.

History shows that superior aircraft did reach operational units. However, there were employment problems that would have increased had Germany deployed more of the advanced aircraft. First, Hitler was overtly hostile to any defensive measures. This, combined with his control of advanced production, meant fighter and antiaircraft deployments were piecemeal. Hitler believed a more effective defense was to meet terror with terror, causing him to deploy his new weapons in less than optimal ways.[67] Once airborne, the defenders did have the benefit of aircraft acting as airborne command posts to coordinate attacks.[68] However, it was only a local measure and did not affect the overall defense of Germany because it could not provide theater-wide situational awareness. Galland sums it up best: "We not only battled against technical, tactical, and supply difficulties, we also lacked a clear picture of the air situation, of the floods coming from the west—absolutely necessary for the success of an operation."[69] More wonder weapons inefficiently employed would not have improved the situation. They likely would have caused more confusion for the limited C2 system coordinating attacks on the bomber forces.

Except for Goering and Milch, the Luftwaffe did not know about the Me 262's development until it was already in advanced testing. There was no way for the units to develop training or tactics for the new aircraft if the operators did not know the planes were coming.

The final reason for the ineffectiveness of the wonder weapons comes from their secretive development and combat employment. Except for Goering and Milch, the Luftwaffe did not know about the Me 262's development until it was already in advanced testing.[70] There was no way for the units to develop training or tactics for the new aircraft if the operators did not know the planes were coming. Often a pilot's first experience with the aircraft would be in combat, with less than optimal results. Additionally, when Galland set up his JV-44 jet fighter unit, it was not subordinate to anyone—many felt it had finally shaken the micromanagement that had ruined the program. However, Hitler would not allow JV-44 to have contact with other units, fearing their defensive mindset would contaminate strike units.[71] This isolation was an effective quarantine, meaning the best pilots could not share their skill and experience with other units, especially those trying to employ complex equipment with rookie crews. The new pilots then had little chance to improve except in one-sided combats with Allied fighters. Lack of tactics for the advanced aircraft and the moratorium on sharing expertise would have made more wonder weapons just as ineffective and would have given the Allied fighter pilots easier targets.

The Luftwaffe was unable to prove what it could have done with more wonder weapons, as production difficulties kept it from reaching the operational numbers

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that could have made a difference. Incompletely integrated technology, decreasing crew skill and experience, a deficient training program, and Allied attacks kept the advanced aircraft in service from effective operations. These problems would have handicapped greater numbers as well. Galland's comment at the war's end concludes it well. When his unit finally received Me 262s, he said:

> But this was 1945! In the middle of our breakup, at the beginning of our collapse! It does not bear thinking what we could've done with jet fighters, 30-millimeter quick-firing cannons, and 50-millimeter rockets years ago, before our war potential had been smashed, before indescribable misery had come over the German people through the raids.[72]

Fortunately for the Allies, the wonder weapons did not arrive on the scene until it was too late to make their mark.

The V1 and V2 Case

So far, we have seen several reasons why the wonder weapons would not have made a difference, even if Germany had deployed them in significant numbers. However, there is a case showing two wonder weapons Germany managed to develop, produce, and use in large quantities: the V1 cruise missile and V2 ballistic missile. This section will further prove the point that greater numbers of advanced armaments would not have made a difference by demonstrating how 35,000 V1s[73] and 10,000 V2s[74] could not change the war's outcome. The primary reasons were the missiles' technology, the theory behind their combat employment, and production interference. It is logical to assume the other wonder weapons would experience similar problems had Germany mass-produced them.

The first topic is numbers. As we saw earlier, Germany built 35,000 V1s and fired 9,200 of them, killing 6,184 people in England.[75] Likewise, 1,300 V2s hit England between October 1944 and March 1945, killing more than 2,700 and wounding 19,000. V2s had some success degrading Allied logistics with attacks on Antwerp but, on the whole, were another futile effort to turn the war in Germany's favor. Why couldn't huge numbers of these weapons make a difference, especially considering the V2 was unstoppable?

No other countries developed cruise or ballistic missiles during World War II. In fact, the United States and Soviet Union used both the V1 and V2 to create their own systems after the war.

No other countries developed cruise or ballistic missiles during World War II. In fact, the United States and Soviet Union used both the V1 and V2 to create their own systems after the war. However, closer examination reveals the missiles had several of the other wonder weapons' problems: relatively low technology, little systems integration, and minimal reliability. To start, Allied fighters could easily catch the slow (400 miles per hour) V1s and shoot them down. If they were out of ammunition, a few pilots dared to tip the V1s over by placing their wing under the V1's wing and then flicking it up, causing the missile to spin out of control.[76] The British set up dedicated warning nets to detect the incoming V1s and then sent out interceptors. Royal Air Force (RAF) action thus dispatched 4,000 of the 9,000 V1s fired.[77] Interestingly, the British kept all their new Meteor jet fighters in England to deal with the missile threat.[78] However, this was not a victory for the wonder weapons,

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as the Meteors did not have the range to escort bombers and were not ground attack aircraft either (the Allies already had plenty of aircraft to cover those missions). Vulnerability to interception was not the V1's only problem. A greater fault afflicted it and the V2: lack of accuracy.

While the English could not shoot down the V2s, they and the V1s that penetrated the defenses were extremely inaccurate: V1s had a 12-kilometer circular error of probable (CEP), while V2s had a 6-kilometer CEP,[79] meaning only half the rounds fired fell in a circle with the CEP's radius. The reason was neither *advanced* system had a guidance computer. The V1 flew straight at a constant speed (the engine actually lost efficiency as it burned, keeping the missile at the same speed even though it was getting lighter as it burned fuel),[80] then plunged to earth after the primitive air log propeller in its nose had counted the appropriate number of rotations. Once the air log reached the preset number, it locked the V1's controls so it would dive into whatever was below.[81] The Army's V2 was designed as long-range artillery[82] and essentially lobbed its warhead beyond gunfire's range. Considering the problems of ballistics, high-speed reentry, and rocket efficiency variations from poor fabrication, it was lucky any V2s hit their targets. Even a simple guidance system would have made the missiles more accurate and, certainly, more a threat to Allied targets. These limitations point to the fact that the V weapons were not that technologically advanced—an issue that reduced their effectiveness.

The V weapons caused relatively few deaths or damage, especially compared to the Combined Bomber Offensive.

The V weapons caused relatively few deaths or damage, especially compared to the Combined Bomber Offensive. Three reasons caused the lack of destruction. First, the horrendous accuracy made pinpoint attacks impossible. The Germans did develop a missile-mounted transmitter that stopped signaling when the V1 hit the ground, allowing corrections for the next shot.[83] The ever-resourceful British electronic-warfare teams countered this tactic, spoofing the signal to make the weapons miss by even more.[84] Second, both missiles had very short range: the V1 required launch sites in Holland, with the V2s not much farther back. Even that close to England, the missiles could not reach the heavy industrial areas. Once the Allies liberated Holland, then the rest of Western Europe, the missiles had no way to reach their targets. The only exception was He 111-launched V1s (the first air-launched cruise missiles), which were impractical because of Allied air superiority.[85] Third, the Allies knew well the capabilities of the V1 and V2, capabilities that would increase if Germany could improve the missiles' guidance. The RAF and the US Army Air Forces also knew where the Germans built and launched the weapons and subjected the installations to unrelenting attack. Once again, the Combined Bomber Offensive created a final obstacle for wonder weapons and made a system that was not making a difference completely useless. With their inherent problems, why then did Germany focus so many resources on building and launching the V weapons? The answer lies in the unique political and military views of the Nazi party.

The lack of accuracy did not bother the Nazis, as the weapons' main purpose was terror, a goal that denied the Germans any chance of effectiveness. Hitler believed

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they were the *decisive weapons* that would bring him ultimate victory by destroying England and the Allies' will to fight.[86] Had Hitler looked at his own people, he would have seen the Combined Bomber Offensive's tremendous destruction had not broken their spirit,[87] even under daily attacks that dwarfed the entire V1 and V2 campaigns. In addition, he should have learned a lesson from the Battle of Britain, where his extreme efforts could not touch the English spirit. While the V weapons did cause psychological strain,[88] the V1 counter campaign actually had a solidifying effect on British morale. The population eagerly tracked the operation's progress, hailing each interceptor's kill, especially the *tippers.*[89] England had no counter for the V2, but the people soon realized the low threat from the inaccurate missile, seeing it could only strike populated areas. They had dealt with terror raids before, and with the war going the Allies' way, they saw the V2s for what they were: weapons that could terrorize but not effectively hurt the Allies. Therefore, Hitler's purpose for employing the V1 and V2 actually helped the Allies' cause. At the same time, the weapons hurt Germany's chances for developing other wonder weapons.

The V weapons programs impaired other advanced projects by consuming vast resources and manpower that Germany could have used to make effective armaments. When Hitler saw a V2 demonstration film on 7 July 1943, he directed that the program receive whatever labor and materials it needed. The program cost more than 5 billion reichsmarks and absorbed tens of thousands of workers (many of them slaves, an additional factor in the poor workmanship)—enough to have produced 24,000 aircraft.[90] The effort compromised the rest of Germany's war economy and prevented programs from having real strategic worth. One such weapon was the Hs-117 radio-controlled surface-to-air missile,[91] something the Germans needed to counter the Combined Bomber Offensive. The resource expenditure did not stop with the basic missile. Germany pursued two extreme measures to improve the weapons. First, it developed a manned V1 much like the Japanese Ohka kamikaze rocket plane. Unlike the Japanese, the Germans found few volunteers to man the aircraft, even after a test program led by famous pilot Hannah Reitsch.[92] One can predict the program would have improved accuracy but would have resulted in many deaths from Allied interception before the missiles reached their targets. The second scheme involved a Type XXI submarine (another wonder weapon) towing a V2 that rode in an underwater launch center to its liftoff point near the US east coast.[93] Although the designers knew it would have minimal accuracy, they justified the expenditure by saying the weapon's harassing effect would have strategic and political results. Germany produced one of these weapons in the 5 months preceding the war's end but never used it. These problems highlight Germany's complete lack of strategic vision and judgment of what made a successful weapon. The same problems would have affected the other wonder weapons had they reached mass production and deployment.

The V weapons programs impaired other advanced projects by consuming vast resources and manpower that Germany could have used to make effective armaments.

The V weapons were the only wonder weapons that saw mass production and employment yet had insignificant effect on the war's outcome. The basic problems

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of integration, poor accuracy, futilely striking morale, and wrongly prioritized expenditures made these wonder weapons, at best, useless, and, at worst, a war loser for Germany. We can see the same problems affecting the other advanced projects as well, showing again what little effect they would have, even in large numbers. In the final analysis, the wonder weapons only promoted the fantasy of the next technological breakthrough that would change the war.[94] This fantasy was at the expense of practical weapons that could have given the Luftwaffe and Germany a real chance at victory.

Relevance for Today: The US Defense Transformation

Examining the past for historical interest is fine, but it has true value when one applies it to similar events happening today or that could happen in the near future.

Examining the past for historical interest is fine, but it has true value when one applies it to similar events happening today or that could happen in the near future. Adapting a common phrase, one can see that those who do not learn from the past are doomed to repeat it or, at least, will miss opportunities. World War II Germany attempted to transform its war effort with technology but did not have the strategic vision, operational integration, or production capacity to pull it off. One can easily draw a parallel between Germany's efforts and the current US transformation employment. This section will examine the ongoing US military transformation with respect to producing technology, integrating it with other innovations and current weapon systems, then using it to execute national security strategy in a challenging world. Additionally, it will compare German efforts to do the same, showing the pitfalls on the way toward dominance in all phases of warfare.

Producing high technology has been America's trademark since World War II. During the Cold War, the United States counted on quality to defeat the Warsaw Pact's quantity. Whereas the Germans canceled all programs that could not be completed within 1 year, Secretary of Defense Donald Rumsfeld wants to cancel all projects that do not take the military to the next level.[95] This is a result of the US strategic orientation toward the long term, rather than focusing on near-term issues. However, the Department of Defense (DoD) must avoid going to the other extreme, because putting all its hope in next-generation weapons will be to the detriment of current and proven technology. Two reasons support this point. First, advanced technology is very expensive, making it difficult to replace combat losses.[96] The Luftwaffe demonstrated this lesson, and the DoD would be wise to learn it. Second, wars are now *come as you are*, leaving little time to develop new weapons to meet current threats—it could be disastrous to get caught between technological advancements. The key for producing technology is how the United States spends money. Germany could not control its wonder weapons' escalating costs, and it skewed the entire war economy. If the DoD cannot control the exponential cost growth in next-generation weapons, it could price itself out of the defense business altogether. The United States needs to make astute decisions regarding successor weapon systems, in some cases making ruthless choices to ensure it spends money in the right places to produce effective forces within a reasonable time.[97] Producing

technology is important; more crucial is how the military integrates that technology into operations.

Germany failed to integrate its world-leading technology into effective weapon systems, leading to arms that were not as effective as they could have been. Component shortcomings, lack of aircrews, and maintenance problems contributed as well. The current DoD transformation has a better focus. According to Rumsfeld, transformation is more than building high-tech weapons. It is about finding new ways of thinking and fighting. The goal is not to transform within 1 year or even 10 years—it is an ongoing process.[98] While DoD works the process, it cannot assume new is always better, because integration will always limit high technology[99] until all weapon components are at the same development level. Additionally, a smaller force of less sophisticated weapons leaves more money for maintenance and upgrades.[100] A good example of this is the recent reduction in the B-1 force, allowing the Air Force to upgrade the remaining bombers to be more effective against moving and time-critical targets. Relatedly, buying versatile weapons can bring down costs, improve integration, and increase effectiveness. The new push for an F/A-22 (vice an F-22) shows the Air Force is moving toward versatile platforms.[101] Integrating the technology is vital; equally crucial is taking care of the people who run the weapons. It would be a mistake for DoD to neglect training, retention, and services to pay for new weapons. Germany was unable to use its advanced aircraft for want of experienced aircrews. Current weapons are even more advanced and require the best people to make them effective when the military uses them.

Developing, producing, and integrating technology does no good unless the United States uses its transformed power in an effective way. There are four ways it can employ power to make the fullest use of the transformation. First, the Services need clear concepts of operations (CONOPS) to guide both using the technology today and as a roadmap to the future.[102] Without thoroughly developed CONOPS describing how to employ new weapon systems to meet long-term goals, the DoD runs the risk of short-term thinking. The Air Force is pursuing eight CONOPS, covering everything from space to global strike and mobility, to realize its vision.[103] Second, the military must use a combination of old and new technology to get the job done. For example, Global Positioning System-guided munitions are superior high-accuracy weapons. However, they are much less effective without a man in the field using simple sighting equipment to find and pass target coordinates to orbiting aircraft. This supports the idea of not placing all hope in fantastic equipment. Third, while fighting the war on terror, the United States cannot become stuck in a defensive mindset like Germany did and lose its capability to strike its enemies. The Secretary of Defense and many other high-level government officials have stated the best defense against terror is a good offense,[104] an appropriate attitude that the United States has so far followed. Moreover, America should be realistic in planning to employ its power. The DoD has finally moved away from the two major wars scenario to a more realistic approach of fighting one major conflict while holding ground in

German Wonder Weapons: Degraded Production and Effectiveness

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other contingencies.[105] The DoD is doing this by replacing its Cold War threat-based approach with a capabilities-based view. This concept looks beyond current uncertain needs in order to maintain strategic flexibility and resistance to asymmetric surprise.[106] Thus, the capability-based approach directs readiness for the most likely military needs instead of preparing to counter threats that do not pose a realistic danger. Finally, the United States is strongly advocating effects-based operations (EBO).[107] These operations concentrate on achieving effects that will force the enemy to do our will, instead of just destroying targets that produce arbitrary effects. This requires the military to integrate all systems to find, target, and attack those centers of gravity that will make maintaining the status quo impossible for our adversaries. Attacks requiring pinpoint accuracy to eliminate collateral damage are tailormade for advanced technology, but the United States must ensure it is hitting the right things. Germany squandered its ballistic and cruise missiles trying to attack British morale and ultimately did not attain its goal. The same fate awaits the United States if it does not do its homework to find those things that truly hurt its enemies.

Developing technology while not becoming over reliant on it, integrating advanced weapons to get full use out of all systems, and using the systems most effectively will allow the United States to avoid Germany's problems. Building a transformation to keep America ahead lets it fight on its terms and keeps enemies off balance and struggling to catch up. The United States must be ready for asymmetric threats and let other countries fantasize about finding their own wonder weapons to change their fortunes. If the DoD transforms correctly, it will not only be ready for them but also may even deter adversaries from using counter technologies against America.

Nazi Germany possessed the technical prowess and industry to produce several wonder weapons during World War II. Its jet and rocket fighters, guided missiles, and cruise and ballistic missiles were all ahead of their time and superior to Allied armament. However, Germany could not transform its military into an effective force to stem the rising Allied tide for several reasons.

Conclusion

We now know the dominant weapons on the battlefield are the ones that can be mass-produced, operated by motivated fighters, kept in action with spares and supplies, and used in concert with other weapons.[108] Ignoring the above advice in pursuit of superior weaponry courts disaster. In the words of General George S. Patton, "How easily people can fool themselves into believing wars can be won by some wonderful invention rather than by hard-fighting and superior leadership."[109] Nazi Germany possessed the technical prowess and industry to produce several wonder weapons during World War II. Its jet and rocket fighters, guided missiles, and cruise and ballistic missiles were all ahead of their time and superior to Allied armament. However, Germany could not transform its military into an effective force to stem the rising Allied tide for several reasons.

Germany's first significant problem was producing and deploying its wonder weapons. Many times, Nazi politicians interfered in projects, creating obstacles to efficient production. Further, the military itself played too large a role in design and production specifications, with changing demands making any kind of mass production nearly impossible. Corruption also played a role in keeping incompetent

designs afloat, taking valuable production capacity away from truly useful projects. All this boiled down to a lack of strategic vision rising from the Germans' overconfidence in quick victory, a problem that plagued both weapons production and military operations. Finally, the Combined Bomber Offensive made an already horrible system untenable and was the straw that broke Germany's wonder weapons capacity.

Weapons are no good if a country cannot use them. Had Germany actually mass-produced its wonder weapons, it is doubtful they would have done any good. First, the weapons were not that advanced as systems because of German industry's failure to integrate them into total packages. Second, long-term pilot losses led to decreasing crew experience. This, combined with an inadequate training system, meant there were insufficient pilots to fly the wonder weapons. The Luftwaffe compounded the problem late in the war when it completely stripped its training units, sending all pilots and planes to fight. Third, Germany's focus on defense left it little capability to conduct offensive operations to truly hurt the Allies. When it did attack with its only mass-produced wonder weapons, the V1 and V2, it sought only terror effects. Its targeting mistake made the V missiles even more ineffective than their inherent inaccuracy dictated. Additionally, the missile program diverted enormous resources from other projects that could have dented the Allies' progress. In the end, the blade that cut through Poland, France, and the rest of Europe could not be sharpened by the wonder weapons and was ultimately too brittle to survive the exhausting conflict.[110] It dulled against the Allies' steel and concrete and was shattered in its turn, ending any chance of German victory.

The lesson Germany failed to learn is relevant today, as the United States moves to transform its military. We must heed the lesson that it is not enough to produce high technology with a short-term strategy. Instead, the United States must make careful choices on what to develop in the budget-constrained economy and fully integrate new weapons with the support systems and people on which they depend. Then it must effectively and realistically employ its transformed military to keep adversaries off balance. Producing, integrating, and employing new wonder weapons to strike targets for effects rather than brute destruction will bend adversaries to US will and allow the United States to attain its national security objectives. Germany lost the opportunity to become and remain a truly advanced power. America is totally dominant in many factors but must continue its ongoing transformation process to stay ahead and provide unmatched military effectiveness.

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Global Supply and Maintenance for the Berlin Airlift, 1948-1949

Colonel Frank Howley, the tough, irrepressible commander of the American military garrison in Berlin, watched with wonder the first Douglas C-47 Skytrains land with food for the people of Berlin. "They wobbled into Tempelhof," he later wrote,

> Coming down clumsily through the bomb-shattered buildings around the field … the most beautiful things I had ever seen. As the planes touched down, and bags of flour began to spill out of their bellies, I realized that this was the beginning of something wonderful—a way to crack the blockade. I went back to my office almost breathless with elation, like a man who has made a great discovery and cannot hide his joy.[2]

Colonel Howley had indeed witnessed something special. On 24 June 1948, the Soviet military had clamped a tight blockade on the land and water routes between the Western occupation zones of Germany and the Allied sectors in Berlin. Three air corridors also connected Berlin with the occupation zones. Taking advantage of these, Lieutenant General Curtis LeMay, Commander of the United States Air Forces in Europe (USAFE), had already begun flying supplies to the military garrisons in Berlin two days before the blockade. But something more was needed. General Lucius D. Clay, the American military governor in Germany, and General Sir Brian Robertson, his British opposite number, turned to airpower as the only means of feeding and supplying the 2.5 million German citizens in Berlin. The result was *Operation Vittles*, which, together with the Royal Air Force's *Operation Plainfare*, would soon become the greatest humanitarian airlift in history.

The airlift began as a short-term expedient to buy time for Western diplomats to negotiate an end to the blockade that threatened to starve 2.5 million Berliners, but it soon grew into a huge, well-oiled machine that delivered enough food, supplies and, above all, coal, to keep the city alive and to ensure freedom for its people. At the beginning, the US Air Force had barely a hundred weary C-47s in

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On 28 July 1948, the US Air Force's premier air transport expert, Major General William H. Tunner, arrived in Rhein-Main and took command of the airlift. Tunner and his staff of experienced air transport experts—who had learned their business on the Hump airlift to China during World War II—imposed order on all aspects of the airlift.

Loading C-47s during the Berlin Airlift.

Germany. LeMay knew these were not enough and he quickly requested strategic air transports, four-engine Douglas C-54 Skymasters. As these joined the airlift in increasing numbers, the amount of cargo delivered increased dramatically and continued to climb despite all obstacles.

On 28 July 1948, the US Air Force's premier air transport expert, Major General William H. Tunner, arrived in Rhein-Main and took command of the airlift. Tunner and his staff of experienced air transport experts—who had learned their business on the *Hump* airlift to China during World War II—imposed order on all aspects of the airlift. Tunner required the careful coordination of every aspect of the airlift, including detailed procedures and exact duplication and precise execution of each phase of the operation, from loading cargo to the return landing. Aircraft maintenance teams, aircrews, supply personnel, and thousands of lesser-known activities were sharply regimented. All personnel performed their duties according to strict directives, and statistical charts and tables tracked the process at every stage. Tunner demanded that all activities take place in a constant, unvarying cadence. "This steady rhythm, constant as the jungle drums, became the trademark of the Berlin Airlift."[3]

Ultimately, Skymasters flew the narrow southern corridor at carefully controlled 3-minute intervals, landed in Berlin at the same intervals and returned to their home bases through the center corridor around the clock, 7 days a week. This rate, Tunner

noted, "provided the ideal cadence of operation with the control equipment available at the time." He explained, "At 3-minute intervals, this meant 480 landings at, say, Tempelhof, in a 24-hour period. Under ideal circumstances, this schedule could mean 1,440 landings daily at three air fields."[4] Tunner viewed the corridors between Western Germany and Berlin as a conveyor belt with aircraft spaced evenly along the route. All the aircraft moved at the same speed, executed their maneuvers at the same spot and followed the predetermined schedule to the second. Like a conveyor belt, the airlift could be slowed down or sped up as necessary, but it was relentless in its regimentation.[5]

On 15 October 1948, the US Air Force and the Royal Air Force united Operation Vittles and Operation Plainfare under the Combined Airlift Task Force (CALTF) commanded by General Tunner, with Air Commodore John W. F. Merer as his deputy. Establishment of the CALTF gave Tunner complete operational control of the airlift. The results were unprecedented; tonnage continued to climb, even in the face of the winter of 1948-1949, which Soviet leaders—and not a few of their Western counterparts—believed would bring the airlift to a halt. By spring 1949, the airlift had won; its victory was punctuated by the *Easter Parade* in mid-April 1949 when it delivered 12,941 tons in 24 hours. This showcased airlift's capacity to deliver huge amounts of cargo and demonstrated conclusively the ability of Tunner's system to manage an unprecedented density of traffic. Thanks to the Berlin Airlift, the Soviet Union had no options. Its leaders had to negotiate over the future of Germany with the Western powers on even terms. On 12 May 1949, the Soviet Union lifted the blockade. The Western powers continued to operate the airlift until 30 September 1949, stockpiling enough food and other necessities to forestall future Soviet threats to the city.

Major General William H. Tunner, Commander, Combined Airlift Task Force, is considered the father of modern airlift.

Maintenance and Supply for the Airlift

An enormous logistical endeavor in its own right, the Berlin Airlift was made possible by a massive logistical effort that stretched from the flight lines at the airfields in Germany, through depots in Germany and England, to maintenance and supply facilities across the US. The effectiveness of this system was critical to the success of the airlift. The most serious problem faced by the airlift,

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Global Supply and Maintenance for the Berlin Airlift, 1948-1949

The worst problem with the C–47s, though, was their inadequacy for the job expected of them. Their three-ton cargo capacity was insufficient and their operational performance was inferior to the larger, four-engine C–54s.

Completed maintenance dock area for repair of C-54 aircraft engines, 20 September 1948.

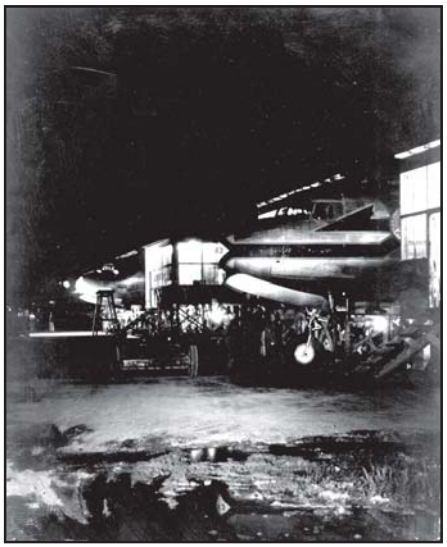
other than flying under inclement conditions, was the servicing and maintenance of the airplanes that performed the work.[6]

From the beginning of the airlift through the arrival of the first C–54s, C–47s were air transport in Europe. While much beloved in Air Force (and Army Air Force) lore, they were unpopular in the airlift role. USAFE's Skytrains were all more than 5 years old and had more than 2,000 flying hours, most under wartime conditions. Some still wore the black and white vestiges of D-Day invasion stripes that dated from 1944. Their age and worn condition frustrated the maintenance and supply personnel who had to keep them in the air. In one example, intergranular corrosion and cracks in the landing gear bracing strut attachment fittings grounded many C–47s at a cost of some 850 hours in inspection and maintenance. Further, the severe shortage of parts threatened routine maintenance and technical order compliance despite every attempt to requisition them. The worst problem with the C–47s, though, was their inadequacy for the job expected of them. Their 3-ton cargo capacity was insufficient and their operational performance was inferior to the larger, four-engine C–54s. The first Skymasters landed at Rhein-Main on 1 July, and, as additional numbers arrived, they gradually replaced the Skytrains. The last C-47

left the airlift on 30 September. Reliance on a single, standard airplane not only enabled Tunner and his staff to streamline every aspect of operations on the airlift but it vastly simplified supply and maintenance.[7]

Maintaining the C–54s still presented serious problems. First, since the few Skymasters that had operated in Europe prior to the airlift were assigned to the Military Air Transport Service (MATS), USAFE lacked the means to support them. Supplies and parts for the aircraft were not part of the USAFE supply system; maintenance facilities capable of handling them were in short supply and few mechanics had experience with the big birds. Second, the squadrons deployed from the US brought only a limited number of mechanics and few parts with them; most ground personnel and stocks of supplies arrived by ship, taking several weeks to reach Europe. Conditions on the airlift compounded these problems. The Skymaster had been designed and built to fly passengers over long distances, a mission that featured few takeoffs and landings and long hours at a standard cruising speed. Now, Tunner called upon them to make a large number of short flights carrying extremely heavy loads. Frequent takeoffs under maximum power strained engines and wore out parts; repeated landings with 10 tons of cargo wore out tires, burned up brakes, and severely stressed the C–54's fragile nose gear. The airlift placed a tremendous burden on engines and airframes and ate up spark plugs, brakes, and tires at an incredible rate. The pounding caused by the frequent landings loosened bolts and rivets and fractured metal pieces. The Air Force determined its stock levels by calculating the wear and tear on aircraft flying a standard number of hours per year. Skymasters on the Berlin airlift used up a year's worth of flying hours in a few weeks, placing demands on the system far in excess of what it was capable of filling.[8]

The limited inventory of C–54 parts Air Force-wide compounded the situation. There were simply too few parts to stock the supply pipeline and ensure a steady flow of parts so that they were immediately available when required. The shortage of parts in the pipeline system meant that standard practices, like delivery of parts by ship, were insufficient to maintain supply levels, and thousands of tons of parts, equipment, and supplies had to be flown from the US to Europe.[9]



Looking down the line of maintenance docks during night crew operations of the C-54 aircraft maintenance project at the Oberpfaffenhofen Air Force Depot.

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Cycle maintenance on the C–54s called for preventive maintenance during standardized inspections at carefully determined points—daily and at 50 hours, 200 hours, and 1,000 hours—to ensure the integrity of the aircraft and its safe performance.

USAFE Letter 65-60, published on 19 August 1948, established basic supply and maintenance procedures for the Airlift Task Force (Provisional). Essentially, all common items of Air Force supply came from USAFE's primary supply facility, Erding Air Force Depot. Erding also maintained the necessary stocks to support depot-level maintenance for C–54 engine accessories, instruments, surfaces, and electronic components. Task Force Headquarters designated Rhein-Main as the specialized supply depot for C–54 support, and directed it to establish a 60-day supply level for the big aircraft. Oberpfaffenhofen Air Force Depot in Bavaria established electronics maintenance for radios and radars. When American units were based at two airfields in the British zone of occupation—operations began at Fassberg in August and at Celle in November 1948—they requisitioned C–54 parts from Rhein-Main. Finally, Erding supplied equipment for the initial installation of AN/ARC–3 radios in the C–54s. Replacement parts and spares for the radio came from Rhein-Main.[10]

In addition to its functions as a supply depot, Erding also accomplished sheet metal work, repaired aircraft instruments and performed special work impossible at other bases, like the elimination of fuel-line leaks. Erding's direct support of the airlift was especially important during the summer of 1948, when it had to send many of its enlisted mechanics to reinforce the shorthanded maintenance crews servicing the C–47s at Wiesbaden.[11]

Cycle maintenance on the C–54s called for preventive maintenance during standardized inspections at carefully determined points—daily and at 50 hours, 200 hours and 1,000 hours—to ensure the integrity of the aircraft and its safe performance. Maintenance control personnel carefully scheduled these inspections and thoroughly documented the status of the airplane, the deficiencies identified, and the repair actions taken. Maintenance on the airlift was a continuous process that operated 24 hours a day, 7 days a week, and precise scheduling followed accurately was the key to keeping the airplanes flying. The maintenance control unit within the airlift headquarters constantly updated a color-coded control board, displaying the status of each aircraft and providing the overall status of the airlift fleet at a glance.[12]

Maintenance planning by the end of July 1948 called for field maintenance to be a theater responsibility conducted at the flying bases. The critical 200-hour inspections would take place at Oberpfaffenhofen until a World War II air depot at Burtonwood in England reopened for operations. The 1,000 hour inspections would be the responsibility of Air Materiel Command in the US.[13]

Mechanics at the bases and depots in Europe accomplished their work in terrible weather. Rain, fog, and cold—combined with poor facilities, long hours, and shortages of tools and parts, and intensified by the tremendous pressure of keeping the airplanes flying—made maintenance a miserable, nasty job. And the lack of amenities in the form of proper housing and, often, poor food did little to inspire the men. Major Vance Cornelius, a veteran maintenance officer at Rhein-Main,

reported the state of affairs was little different at his base than those Eighth Air Force mechanics had faced during World War II, except Eighth Air Force had a better supply of parts.[14]

In addition to the living and working conditions, maintenance on the airlift suffered severely from deficiencies in the number, experience and ability of the mechanics and technicians available, especially early in the operation. Inexperienced personnel were a special problem. Not only were they inefficient, but they could double or triple the time required for even the simplest of repairs. Inexperience cost the airlift hundreds of hours of flying time. The situation improved over time, thanks to better screening of personnel sent to Germany and an intensive on-the-job training program established by the CALTF, but as late as April 1949, a newly arrived mechanic fresh from the C–54 course at Keesler Technical Training Center could encounter a sergeant mechanic who had never been taught to change the carburetor on the R-2000 engine. Further, the C–54 squadrons were not manned to support a round-the-clock operation, and the Air Force was unable to provide enough mechanics, especially trained ones, to provide all the support necessary. Ultimately, the personnel shortages forced USAFE to recruit German nationals, most former Luftwaffe mechanics, to serve with the airlift. Since few spoke English and all lacked experience with C–54s, this step required translating maintenance manuals, technical publications and inspection checklists into German and establishing an intensive training program.[15]

The best evidence of the progress made in developing a strong maintenance capability came between April and July 1949 when the airlift averaged better than 190,000 tons of cargo per month, some 60,000 tons per month more than during the previous 4 months, although the number of aircraft assigned to Operation Vittles remained virtually unchanged.[16]

Field Maintenance

Airlift maintenance personnel tended to follow standard Air Force practices, but this often proved impossible. The shortage of personnel, especially early in the airlift, prevented the assignment of a crew chief and crew to each aircraft at Rhein-Main. Consequently, maintenance planners had to alter techniques to make the most of the scarce mechanics.

Maintenance at the field level was divided into three functions. First, each aircraft received a daily preflight check. Second, *turnaround* maintenance provided routine servicing when an aircraft landed. It also addressed pilot complaints. Third, maintenance personnel conducted routine checks at 50, 100, and 150 hours. To accomplish these checks, a squadron had 148 maintenance personnel assigned—often many less were on hand—divided into three shifts working 12 hours on and 24 hours off. Each shift, in turn, was further divided into three crews. An *alert crew*, usually 12 to 16 men, carried out the preflight checks of the airframe, engines, landing gear, fluids, and electrical systems. They also inspected the radio and radar systems.

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Inspection and maintenance of airlift planes at Oberpfaffenhofen Air Force Depot.

The alert crews also conducted turnaround maintenance. In this process, aircraft pilots notified the tower of any complaints or problems before they landed. If the problem was minor, the alert crew called for fuel, oil, and another load and accomplished repairs on the flight line. If the work was beyond their capability, they turned the aircraft over to the appropriate crew that specialized in engines, electrical systems, hydraulics, radios, props, or other systems.[17]

The third maintenance function, 50-hour inspections, provided preventive maintenance designed to reduce the need for unscheduled maintenance by identifying and correcting problems before they became serious. This work included a thorough cleaning of the aircraft, the replacement of spark plugs, an oil change, and an inspection of the airframe, engines, and aircraft systems. The 50-hour inspection usually took about five hours to complete.[18]

200-Hour Inspections

With each aircraft flying an incredible number of hours, the Skymasters reached the 200-hour inspection mark quickly. This inspection was critical to the performance of the C–54 and the life of its airframe. It could not be omitted. And since the aircraft had to be removed from the operation for several days, it rapidly became a major concern for airlift planners. To standardize and accelerate the process, USAFE

planners decided to concentrate 200-hour inspections at one location. They reopened a former World War II air depot at Burtonwood in northern England for that purpose, because it had sufficient space and facilities for a complete inspection line. Opening Burtonwood and readying the facilities took time, however, and on 6 August, Tunner wrote Major General Laurence S. Kuter, Commander of MATS, that 200-hour inspections would take place at Oberpfaffenhofen near Munich until Burtonwood was ready.[19]

The 1421st Maintenance Squadron (Provisional) began operations at Oberpfaffenhofen during the first week of August, and by the 15th the unit had seven officers and 236 men. The first C–54 arrived at Oberpfaffenhofen on 7 August. The 200-hour inspection was much more than a casual evaluation of the airplane. It was a thorough inspection and repair of the aircraft that included a complete cleaning, overhaul, reconditioning, and replacement of worn parts and equipment. First, depot personnel removed all loose equipment, drained the oil and conducted a general inspection. Second, the aircraft exterior was thoroughly washed down with a chemical solution, scrubbed and rinsed with water, while other workers swept and vacuumed the inside of the aircraft. Third, personnel conducted the 200-hour inspection tasks and completed all work necessary on props, engines, ignition, and other systems ahead of the firewall. Fourth, they accomplished the same tasks on all other airplane systems. Fifth, maintenance personnel inspected the hydraulic system, wheels, brakes, and tires. Finally, they serviced the aircraft, replaced all equipment

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The Douglas C-54 Skymaster was the backbone of the Berlin Airlift.

Global Supply and Maintenance for the Berlin Airlift, 1948-1949

During World War II, Burtonwood served as one of the largest modification and repair centers in England. Reduced to a storage area for mothballed RAF bombers after the war, the facility had been allowed to deteriorate: roofs leaked, buildings sagged, equipment rusted and facilities decayed.

removed earlier and conducted a last inspection. USAFE also took the opportunity provided by the 200-hour inspection to make modifications to the aircraft beyond the work done during the inspection. For example, Tunner ordered all unnecessary navigation equipment removed from the C–54s during the inspection in order to save weight and, in another case, beginning in September, depot personnel installed new deicer boots on all C–54s.[20]

The demand for 200-hour inspections soon forced Oberpfaffenhofen to divert 95 percent of its work force to the C–54s. Even this number proved insufficient, a problem compounded by conflicting instructions from the airlift headquarters which set the depot's quota at the completion of four inspections per day, but would only allow 13 C–54s at the depot at one time. Since the time required to repair deficiencies uncovered during the inspection varied substantially from airplane to airplane, the wash racks either had a line of aircraft waiting for service or stood empty. The work force, accordingly, might have to work many overtime hours or might have to be laid off for several days. Recognizing the wash racks as the main problem, Oberpfaffenhofen hired sufficient local German workers in September to handle any influx of aircraft.[21]

In October, Airlift Task Force Headquarters increased the daily quota of aircraft from four to six and assigned Major Jules A. Prevost, a retired maintenance expert from Pan American Airlines recalled to active duty for 60 days, to Oberpfaffenhofen. Major Prevost established a *block system* that slightly increased production; however, at the same time, the depot began preparation to close down the 200-hour inspection program and transfer it to Burtonwood. In all, Oberpfaffenhofen completed 43 aircraft inspections in August, 108 in September, 137 in October and 96 in November. The last C–54 completed inspection at Oberpfaffenhofen on 22 November 1948.[22]

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One measure undertaken at Burtonwood was a weight-stripping program for the D, E, and G series of the C–54s. When weighed, most C–54s were found to be about 300 pounds lighter than the data books listed them. Then, the maintenance crews

removed roughly 2,200 pounds of excess equipment during the renovation process. The aircraft thus emerged from the 200-hour inspection with a payload some 2,500 pounds greater than before. The payoff for the airlift not only lay in increased cargo capacity, but in less complicated maintenance thanks to the removal of equipment.[24]

The transfer of operations from Oberpfaffenhofen to Burtonwood, however, severely impacted the production program at a critical time. In November, when Oberpfaffenhofen produced 45 inspections, Burtonwood completed only 18. The difference was made up by conducting 200-hour inspections at the flying bases: nine at Fassberg, six at Wiesbaden and 24 at Rhein-Main, a total of 102 for the month. This situation, however, was highly unsatisfactory since the bases had to use scarce equipment and facilities and the work was a severe drain on maintenance crews who should have been doing daily maintenance. The situation remained unsatisfactory for several months. In December, Burtonwood accomplished 49 inspections, just over a quarter of those required by the airlift fleet, causing Tunner and his staff considerable worry. Again, the flying bases had to make up the difference: Rhein-Main performed 47 inspections, Wiesbaden 16 and Fassberg nine. Worse, in January, Rhein-Main had to conduct 70 of the 155 200-hour inspections required that month. Additional personnel and equipment subsequently improved the situation at Burtonwood. The depot conducted 85 inspections in February, then more than doubled the total to 177 in March, enabling USAFE to end 200-hour inspections at the flying bases in April, although Rhein-Main continued to do a small number each month. Production at Burtonwood peaked in July 1949 at 256 inspections.[25]

1,000-Hour Inspections

Behind the Berlin Airlift stood the worldwide maintenance and supply capability of the US and, in particular Air Materiel Command, headquartered at Wright-Patterson AFB, Ohio, with its system of depots at Sacramento, California; Ogden, Utah; San Antonio, Texas; Oklahoma City, Oklahoma; Mobile, Alabama; Middletown, Pennsylvania; and Warner Robins, Georgia. A steady stream of airplanes, engines, and subsystems flowed in and out of the depots as the airlift grew. The depot at San Antonio overhauled Pratt and Whitney engines, while those at San Antonio, Middletown, Mobile, and Sacramento reconditioned starters. Generators were reworked at Sacramento, Ogden, Oklahoma City, and Mobile, and propellers were overhauled and reworked at Sacramento, San Antonio, and Warner Robins. San Antonio, Warner Robins, and Sacramento overhauled communications equipment and all of the depots repaired instruments.[26]

The C–54s had to return to the US periodically for cycle maintenance. Cycle maintenance involved a major inspection and reconditioning accomplished at 1,000-hour intervals. At 1,000 hours, for example, personnel conducted a basic inspection of the airframe and systems. The 2,000-hour inspection repeated the basic inspection but included flaps, corrosion prevention, and tightening all bolts. At

The C–54s had to return to the US periodically for cycle maintenance. Cycle maintenance involved a major inspection and reconditioning accomplished at 1,000-hour intervals.

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The airlift's initial plans, based on 126 aircraft, called for 22 to be in the pipeline for the 1,000-hour inspection and 15 for 200-hour inspections at any one time, and all would be carefully scheduled on a regular schedule. The plan worked for the most part, but in November it became apparent that aircraft which had completed their inspections were not being returned to Europe as scheduled. Inspections that had been expected to take an average of 22 days had actually averaged 57.

3,000 hours, personnel repeated the basic inspection and added reconditioning of valves and integral tank sealing. The 1,000-hour cycles continued through 8,000 hours, with changes in the components and systems addressed.[27]

Early in August, the Air Force made about $11M available to Air Materiel Command for contracts to civilian maintenance firms for cycle reconditioning of all C–54s assigned to the airlift, except the Navy R5Ds. The contracts went to three civilian firms, Texas Engineering and Manufacturing Company in Dallas, Texas; Lockheed Aircraft Service Company in Burbank, California, and Sayville, New York; and Aircraft Engineering and Maintenance Corporation in Oakland, California. The first of these began operation around 20 August. Until then, the depot at Middletown accomplished the work. The Navy performed cycle maintenance on its transport aircraft at Moffett Naval Air Station near San Francisco, California. Two C–54s arrived at Middletown on 11 August and eight more were on hand by the 20th.[28]

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The depot maintenance system gradually caught up with the demand for 1,000-hour inspections. By early 1949, the arrival of additional mechanics and parts in Europe increased the number of aircraft on operational status, permitting a more efficient utilization of aircraft and the prompt release of those scheduled for return to the US. Tunner and his staff also brought the problem with delays in 1,000-hour inspections in the US to Secretary of the Air Force Stuart Symington's attention. Symington focused high-level attention on the backlog. As a result, efficiency in processing the aircraft and accomplishing the repair work increased dramatically, while the training of additional pilots and aircrews ensured that the C–54s returned to Germany on schedule. These measures began showing results by mid-February, and by May the difficulties of attending 1,000-hour maintenance had been largely solved.[30]

Aftermath and an Epitaph

Statistics on the Berlin Airlift vary from source to source. The official USAFE summary of the airlift, *Berlin Airlift: A USAFE Summary*, provides perhaps the most complete and accurate data available. According to that source, the Berlin Airlift delivered a total of 2,325,509.6 tons of cargo to Berlin. Of this amount, Operation Vittles delivered a total of 1,783,572.7 tons, while Operation Plainfare delivered 541,936.9 tons. US deliveries included 1,421,118.8 of coal, 296,319.3 tons of food, and 66,134 tons of miscellaneous cargo. British deliveries included 164,910.5 tons of coal, 240.386 tons of food, and 136,640.4 tons of miscellaneous cargo. Among other commodities, the miscellaneous category included 92,282 tons of liquid fuels, mostly delivered by British civilian aircraft operating under contract. British civilian aircraft also delivered 146,980 tons of the cargo included in the British statistics. In terms of percentages, the US Air Force contributed 76.7 percent of the total tonnage, the Royal Air Force transported 17 percent, and the British civil airlift made up the difference with 6.3 percent.

In addition to the cargo flown into the city, the CALTF transported 81,730.8 tons of cargo out of Berlin during the airlift. Of this freight, 45,887.7 tons went in US aircraft while the British flew out 35,843.1 tons. Much of the outbound cargo comprised small manufactured items produced by Berlin industry under incredibly difficult conditions and labeled "Hergestellt im Blockierten Berlin" ("Manufactured in Blockaded Berlin"). The airlift also carried a total of 227,655 military and civilian passengers in and out of the beleaguered city.

The total number of flights made by the airlift also varies somewhat from source to source. The USAFE summary concluded that the total was 277,569 flights, 189,963 flown by the US Air Force and 87,606 by the Royal Air Force. The total number of flights certified the intensity of the Berlin Airlift and the efficiency with which it operated.

The Berlin Crisis of 1948 was the West's first great victory of the Cold War and it had profound consequences. The Berlin blockade proved a disaster for Joseph Stalin and his foreign policies by providing graphic evidence of Soviet ruthlessness and inhumanity. Frightened by Soviet cynicism and brutality, Western Europe took a long close look at the *red menace* and turned to each other and the US for protection. Soviet policies drove these nations to seek safety within a unified defense system and the Berlin Crisis, thus, led directly to the creation of the North Atlantic Treaty Organization. Further, Soviet threats and pressure failed to prevent the establishment of a free and independent West Germany, and, in fact, accelerated the process. By mid-1949, the West Germans adopted a democratic constitution, proclaimed the Federal Republic of Germany and elected a free parliament.

For the US Air Force, the Berlin Airlift demonstrated the need to throw off the *milk-run* mentality of the airlines and earlier military air transport operations. Modern airlift required professional organization and exceptional precision in all aspects

For the US Air Force, the Berlin Airlift demonstrated the need to throw off the milk-run mentality of the airlines and earlier military air transport operations. Modern airlift required professional organization and exceptional precision in all aspects of transportation, communications, maintenance, contracting and supply.

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of transportation, communications, maintenance, contracting, and supply. Above all, the airlift validated the need for large transports designed specifically for use as military transport. The Lockheed C–130 Hercules, Lockheed C–141 Starlifter, Lockheed C–5 Galaxy and McDonnell Douglas C–17 Globemaster III of today's Air Force are the direct descendants of the C–47s and C–54s of the Berlin Airlift and the lessons learned during that great endeavor.

The most appropriate epitaph for the Berlin Airlift flew into Berlin by airplane. On 23 September 1949, an RAF C-47 Dakota landed at Gatow. On its nose, were the words: "Psalm 21, verse 11."[31] For those who knew their Bible, or those who took the time to look, the message with its reference to Stalin's blockade proclaimed victory: "For they intended evil against thee: They imagined a mischievous device, which they are not able to perform."

Notes

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Colonel Karen S. Wilhelm, USAF, Retired

A Historical Perspective on the Future of Military Logistics

The battle is fought and decided by the quartermasters before the shooting begins.[1]

—Field Marshall Erwin Rommel

No matter their nationality or specific service, military logisticians throughout history have understood the absolute truth represented in the above quote. Whether they were charged with supplying food for soldiers, fodder for horses or the sinews of modern war—petroleum, oil and lubricants (POL), they have understood that victory is impossible without them—even if, sometimes, it seemed their vital contributions were forgotten or ignored. None of the great military captains of history were ignorant of logistics. From Frederick the Great to Napoleon to Patton, they all understood the link between their operations and logistics. The great captains also have all understood that history had much to teach them about the nature of the military profession. Yet, military logisticians do not often spend time studying the history of military logistics.

This article is an attempt by one military logistician to derive relevant general lessons from history that might prove of some use in understanding how best to prepare for the future. There are at least three such general lessons. The first of these is the best case operationally is often the worst case logistically. The second is promises to eliminate friction and uncertainty have never come to fruition. And the third is technological change must be accompanied by organizational and intellectual change to take full advantage of new capabilities. While these lessons are not exclusive to logistics, when applied to the understanding and practice of military logistics, they provide a framework for understanding the past and planning for the future.

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Such a framework is vital, now more than ever. Documents such as *Joint Vision 2010*[2] and the follow-on work supporting it are designed to set the course for the US military for the next 15-25 years. Logisticians must not only be proactive in helping set that course, they must use all resources available to ensure it is the right course. A thorough understanding of these three lessons will be of use in this regard.

The Lesson of the Best Case

The German troops marched farther and faster than the peacetime planners had calculated. Since other logistics calculations were predicated on the estimated rate of advance, they were also in error. As a result, the railheads could not be kept within supporting distance of the advancing armies, and heavy transport companies were totally inadequate.

The truth of the sentiment expressed by Field Marshall Rommel was no more apparent than on 2 September 1944 when General George S. Patton's 3d Army ground to a halt from lack of fuel. The subsequent pause by Allied forces after their breathtaking race across France allowed the Germans to regroup and reconstitute their defenses and contributed to the extension of the war by another 8 months. Given the logistical riches of the Allies, one is forced to ask why they allowed this to happen. The answer is their failure to plan for the *best case*.

The historical record shows that September 1944 was not the only instance of logistical failure in spite of logistical riches. Logistics planning for *best case* possibilities is just as important as planning for the worst case in supporting military operations. In fact, the best case operationally is often the *worst case* logistically, and the following historical examples support this assertion.

The first historical example is provided by the German invasion of France through Belgium in 1914. The German troops marched farther and faster than the peacetime planners had calculated. Since other logistics calculations were predicated on the estimated rate of advance, they were also in error. As a result, the railheads could not be kept within supporting distance of the advancing armies, and heavy transport companies were totally inadequate. The failure to plan for the operational best case—a quick breakthrough and advance—could have had a serious impact on the capabilities of the combat forces. In this particular case, it did not because the French halted the German advance before logistics difficulties could. Be that as it may, the evidence indicates the Germans would have had to halt due to logistics problems, and they got as far as they did only through *furious improvisation.*[3]

The second example of failure to plan for the best case is from the North African campaigns of World War II. Both Rommel and the Allies succeeded in putting their operational best case into motion, but ultimately failed because these proved to be the logistical worst case. On at least two occasions, Rommel's offensives achieved massive breakthroughs against the British in the east. He was, however, unable to translate these tactical successes into lasting operational or strategic success because he had completely outstripped his logistics system. Given the distances involved, the primitive transportation infrastructure, the lack of coastal transport capabilities, British air superiority and the lack of effort in correcting these deficiencies, his actions were logistically unsupportable.[4]

Allied efforts in the west after the landings of Operation TORCH were similarly hindered. The failure to effectively plan for the best case was even more egregious

in this instance, however, since they were operating from a position of abundance rather than scarcity. The key objective after the landings was to occupy Tunis before the Germans. The best case operationally was no resistance from French forces and a lightning advance to the east. In order to support this logistically, the Allies would have had to reconstitute and augment the existing rail system and bring enough trucks to fully exploit the limited road network. Yet, they did not allocate enough resources to accomplish the task and support the advance. The number of vehicles transported with each convoy was successively reduced with each iteration of the plan. The focus was on the mere accumulation of supplies—to the point that by the time the plan was executed, the port capacity was approximately two and a half times the combined rail and road capacity.[5]

The third example of the best case planning error, and perhaps the most inexcusable from the standpoint of not having learned from experience, is the Allied advance across France. On 25 July 1944, the Allies were 44 days behind schedule. On 31 August, Patton was 150 miles and 5 months ahead of schedule. The 6,000 trucks of the *Red Ball Express* were using 300,000 gallons of gasoline daily to bring him the 350,000 gallons a day that he needed. By 2 September, he had to stop when the entire improvised system collapsed.[6]

Logistics planning for the breakout from the Normandy beachheads was based on the assumption of a slow, deliberate advance in the face of an orderly German withdrawal. The supply sequence entailed arrival at beach, port or harbor and then transport by rail and truck to supply dumps within tactical distance of the advancing forces. The worst case planning of the logisticians involved the possibility of higher consumption rates than projected. Consequently, the actions taken to preclude the worst case were focused on the accumulation of supplies. As noted above, the actual worst case logistically resulted from the best case operationally. The advance far outstripped the schedule, and transportation capability became the limiting factor. By the time Patton had to halt, POL and ammunition stocks were increasing on a daily basis at the beaches and ports but could not be brought forward.[7]

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The lesson of these three examples can be summarized as follows. World War I marked a turning point for military logistics. Prior to this time, a moving army was easier to supply than a stationary one because food (for men and animals) was the critical element, and the means to obtain it was through foraging. After 1914, the moving army was much more difficult to supply because the critical element was ammunition (and subsequently, POL), for which foraging is not a viable option.[8] The logisticians learned this lesson almost too well. Their focus became the accumulation of supplies before the beginning of operations and their *worst case* became the point when consumption outstripped accumulation. These examples show, however, that accumulation is only half the equation; the other half is transportation. And in modern mobile warfare, the best case for the tactical forces, for example, the greatest rate of advance, is often the worst case for the logisticians supporting them because of limited transportation capability.

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Friction, in other words, is a rather more elegant expression of Murphy's Law. Clausewitz was trying to tell us that military operations exist in the realm of Murphy's Law, and good commanders adjust their plans accordingly, rather than trying to eliminate it.

The Lesson of Friction and Uncertainty

The second historical lesson for logisticians involves the nature of friction and uncertainty. Throughout history, military planners have sought to reduce and even eliminate these two facts of life. The side that has made the greatest strides toward doing so, or at least made greater strides than its enemy, has also taken great strides towards winning. It has become increasingly tempting with our modern technologies to claim proximity to the *Holy Grail* of their actual elimination. *Joint Vision 2010* uses phrases such as *dominant battlespace awareness*, the *uninterrupted flow of information*, and *full dimensional protection*.[9] An even more insidious problem occurs when friction and uncertainty are assumed away without even a cursory reference. Logisticians must be aware of and avoid the pitfalls inherent in this approach.

In *On War*, Carl von Clausewitz first applied the concept of friction to the analysis of war. A series of quotes will serve to illustrate his meaning.

> Friction … is the force that makes the apparently easy so difficult … friction … is everywhere in contact with chance, and brings about effects that cannot be measured…. The good general must know friction in order to overcome it whenever possible, and **in order not to expect a standard of achievement in his operations which this very friction makes impossible**.[10] [emphasis added]

Friction, in other words, is a rather more elegant expression of Murphy's Law. Clausewitz was trying to tell us that military operations exist in the realm of Murphy's Law, and good commanders adjust their plans accordingly, rather than trying to eliminate it.

Logisticians are subject to the effects of friction and uncertainty almost every day, and yet, often forget their effects when planning—or, conversely, try to anticipate and plan around every possible contingency. The earlier discussion of *the best case-worst case* dichotomy serves to illustrate this point as well. Another example occurred during British operations against the Argentines in the Falklands. The ship *Atlantic Conveyor* was sunk by the Argentine Air Force before she was able to unload her cargo of helicopters, airfield construction equipment, and tents. The British plan was predicated on concluding operations as quickly as possible—primarily because of the long lines of communication and the weather. The cargo sunk with *Atlantic Conveyor* constituted a large part of their capability to do so. "Her loss, while removing the means to speed up the operation, made an early termination even more imperative."[11] One is forced to ask why all such vital cargo was loaded on one ship; apparently no one anticipated the effects of such a loss.

The converse *sin* of trying to eliminate friction by anticipating and planning for all possible contingencies can lead to such rigidity that an unanticipated event or last-minute change is completely disastrous. The most obvious example of such a circumstance is the German mobilization for World War I. German logisticians had planned their two-front war in impeccable detail—right down to the number of trains over each bridge in a given time. And when the Kaiser asked Von Moltke to fight

only to the east, against the Russians, Von Moltke answered, "it cannot be done … if Your Majesty insists … [the army] will not be an army ready for battle but a disorganized mob … with no arrangements for supply. Those arrangements took a whole year of intricate labor to complete."[12]

It is tempting to think that we would never do such things. It is tempting to think that it is a different age, that such rigidity is unnecessary now. It is tempting to think that Murphy's Law is *not as bad as it used to be* because we have such wonderful technology. It is tempting, but we would be wrong to draw such conclusions. Friction and uncertainty will remain with us because of three immutable factors.

First, human beings are still an integral part of the logistics system—and human beings make mistakes, and sometimes they act irrationally. They get bored and enter data into their computers incorrectly. They work for 4 or 5 days with minimum sleep and then fail to secure a load properly—and it falls off the truck and is lost. They feel the pressure of ongoing operations where mistakes can cost lives and make even more mistakes. Our friend Clausewitz pointed out that the military machine "is composed of individuals, every one of whom retains his potential of friction."[13]

The second reason that friction and uncertainty will remain with us is that the military is a complex system, in the scientific use of the term. According to Charles Perrow, complex systems are those systems with multiple interactions among parts, procedures and operators. These systems are subject to interactive failures because their designers and users cannot anticipate all the possible interactions and are, therefore, unable to predict all the possible outcomes of any given decision.[14] Such complexity produces surprise. Unforeseen outcomes result when minor variations lead to some unpredictable total. Organizations typically react to these unpredictable results by adding more complexity, thereby exacerbating the problem rather than solving it.[15] One needs only examine the examples discussed earlier, or the surprise achieved by the Japanese at Pearl Harbor, in light of this definition, to see how it holds true for military organizations.

The final reason military logisticians cannot escape friction and uncertainty is that the ultimate *consumer* of military logistics is an enemy who has a vested interest in ensuring the logistics system fails. Again, Clausewitz has captured the fundamental idea: "The whole of military activity must . . . relate directly or indirectly to the engagement. The end for which a soldier is recruited, clothed, armed, and trained, the whole object of his sleeping, eating, drinking, and marching is simply that he should fight at the right place and the right time."[16] The whole object of the logistics system is the same, and the *leaner* we make the system, the scarcer the resources become, the more dependent we are on critical information nodes, the more lucrative a target we have created. The *Atlantic Conveyor* is an example of such a target.

Clausewitz has captured the fundamental idea: "The whole of military activity must . . . relate directly or indirectly to the engagement. The end for which a soldier is recruited, clothed, armed, and trained, the whole object of his sleeping, eating, drinking, and marching is simply that he should fight at the right place and the right time."

The Lesson of Change and Innovation

The third historical lesson for logisticians is organizational and intellectual change must accompany technological change in order to take full advantage of new capabilities. Innovations do not necessarily result from new technologies. New technologies may simply be used to do existing missions better. Innovations occur when new procedures are built around changes in the way organizations relate to each other and to the enemy.[17]

Innovations do not necessarily result from new technologies. New technologies may simply be used to do existing missions better. Innovations occur when new procedures are built around changes in the way organizations relate to each other and to the enemy.

Again, the best case-worst case dichotomy discussed previously is applicable. For example, the problems experienced by Allied logisticians in supporting the breakout and pursuit across France were as much a failure to adapt intellectually and organizationally as anything else. The planners had already experienced the logistical problems of North Africa, but failed to adapt.

The foundation of that failure to adapt was the failure to recognize that a change in operational concept warranted a change in logistical support concept. The mobile tank warfare pioneered by the Germans highlighted the fact that not only had tactical mobility been restored to the battlefield, but it had increased by an order of magnitude. These operations focused on the application of combat power through combined arms and the shock inherent in high-tempo operations. The necessary logistic change was in supporting the high tempo of operations—not just movement, but speed of movement. This was the primary failure of the logisticians—the failure to recognize the need to support the tempo change—an intellectual and organizational change.

The Germans also failed in this regard. Although not apparent in the early campaigns, it was highlighted once they attacked into the wide-open spaces of the Soviet Union. Although the logistics failure was not the sole or perhaps even the primary cause of the German defeat on the steppes of Russia, it was a major contributor.

The Germans had only partially motorized their combat forces and only a small proportion of their logistics support was moved by truck. The remainder was tied to the use of railroads and animal transport. This weakness was masked in the campaigns in Poland and France by the relatively short distances and the rapid collapse of enemy forces. The vast distances encountered on the Russian Front, coupled with the resilience of the Soviet forces, served to expose this problem and caused the German soldiers to suffer horribly.[18]

The noted military historian, Williamson Murray explains that:

> Relations among technological innovations, fundamentals of military operations, and changes in concepts, doctrine and organization that drive innovation are essentially nonlinear. Changes in inputs . . . may not yield proportionate changes in outputs or combat dynamics.[19]

During periods of transition, in particular, there are significant intellectual, organizational and technological changes. The key change, however, must be intellectual change, for without intellectual change, technological change is

essentially meaningless, and organizational change is impossible. Logisticians who grasp at technological change without making the necessary organizational and, more importantly, intellectual changes to fully understand and make best use of new technologies, are doomed to failure. Intellectual change is the requirement to make all others meaningful.

Implications for the Future

In order to examine the implications these lessons hold for the future of military logistics, one must first examine current views regarding the future of military operations. The US military has entered a period of rapid change. Orders of magnitude improvements in technology have resulted in recent attempts to devise long-range plans to incorporate those improvements into new weapon systems and operational concepts. *Joint Vision 2010* and the documents supporting its implementation provide the guidance for thinking about these new concepts.

In the logistics arena, *Joint Vision 2010* explains the concept of Focused Logistics—defined as

> the fusion of information, logistics, and transportation technologies to provide rapid crisis response, to track and shift assets even while en route, and to deliver tailored logistics packages and sustainment directly at the strategic, operational, and tactical levels of operations.[20]

The vision of Focused Logistics includes enhanced mobility and versatility of combat forces anywhere in the world through the elimination of vertical logistics organizations and the use of tailored combat service support packages and pinpoint delivery systems.[21]

Joint Vision 2010 heralds the creation of two other key concepts—dominant maneuver and full dimensional protection, the latter being simply the complete protection of forces and lines of communication *from fort to foxhole*. Dominant maneuver is envisioned as combat forces operating from dispersed locations in sustained all-weather, day or night operations at a decisive speed and tempo. It is "a prescription for more agile, faster moving Joint operations."[22]

The underpinning for all these concepts is the idea of information superiority—"the capability to collect, process, and disseminate an uninterrupted flow of information while exploiting or denying an adversary's ability to do the same."[23] The *Concept for Future Joint Operations* explains further that the view of operations in *Joint Vision 2010* is predicated on the reduction of friction through greater battlespace awareness. This greater battlespace awareness is conceived as a comprehensive and complete view in space and time; using assured, secure and responsive information; and resulting in the capability to predict enemy intentions and actions.[24]

Given the nature of this vision of the future, the three historical lessons that are the subject of this analysis are clearly applicable. In general terms, these documents discuss the need for organizational change and they constitute at least an attempt

The US military has entered a period of rapid change. Orders of magnitude improvements in technology have resulted in recent attempts to devise long-range plans to incorporate those improvements into new weapon systems and operational concepts.

A Historical Perspective on the Future of Military Logistics

at intellectual change. It is too early in the process of change to expect specific suggestions for modifications to existing military organizations. The intellectual change exhibited is part of the current debate regarding an ongoing *Revolution in Military Affairs*. A discussion of whether this revolution actually exists or not is beyond the scope of this article, but the authors of the Joint vision documents clearly believe it does.

With regard to the best case-worst case lesson, it would seem the logisticians of the future would still be susceptible to the effects of this dichotomy. The concept of dominant maneuver is focused on speed, tempo and agility of operations—from dispersed locations. The logisticians' tasks would seemingly be made even more difficult than today. Those who compose this vision of the future would answer that the concept of focused logistics would enhance the mobility and versatility of the logistics forces to the point that they matched that of the combat forces. This is entirely possible, but given that history shows that combat forces are typically ahead of support forces in gaining improved capabilities, it is also entirely possible that logisticians will again find themselves in the position of their worst case being the best case operationally.

It is in the arena of friction and uncertainty that the US military's vision of the future would seem to be most lacking. Combat forces are visualized as smaller and more capable, supported by smaller and more capable logistics forces. The system of forces and support requirements is highly complex and interdependent with little or no slack or excess capability. These forces are to sustain operations around the clock, and success is dependent upon a continuous supply of vast quantities of absolutely accurate information. Although there are occasional disclaimers in the documents to the effect that fog and friction will remain, the concept belies these words—there is no discussion of how the system will cope with or overcome friction and uncertainty.

The only conclusion to be drawn is that the visionaries attempting to set the course for the future of the US military have failed to learn this lesson from the past. They are designing a tightly coupled system of systems. Within that system will exist interdependencies and implicit assumptions that will defy ready understanding and, therefore, result in unexpected outcomes. They are designing a system that is still subject to the vagaries and weaknesses inherent in human beings, but without taking those vagaries and weaknesses into account. They are designing a system which makes the logistics portion such a lucrative target that a potential enemy can have a greater impact by striking against logistics capability than by striking at combat capability. The failure to appreciate the effects of friction and uncertainty has had grave consequences in the past, and we are creating the potential for the same grave consequences.

These three lessons hold meaning for the future of military logistics. History has shown logisticians can fail if they do not understand the best case-worst case dichotomy, if they do not appreciate the need for intellectual and organizational

change and if they do not take into account the effects of friction and uncertainty. While no one should expect history to repeat itself, logisticians can benefit from the study of history with a view toward understanding the errors of the past and the applicable lessons for the future.

Notes

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3. *Ibid.*
4. *Ibid.*
5. Julian Thompson, *The Lifeblood of War: Logistics in Armed Conflict*, Oxford, UK: Brassey's, 1991, 56, 61-67.
6. *Supplying War: Logistics from Wallenstein to Patton*, 213.
7. *Supplying War: Logistics from Wallenstein to Patton,* 212-213, 220-221.
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13. *On War*, 119.
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19. Williamson Murray, "Innovation: Past and Future," *Joint Forces Quarterly*, Summer 1996, 52.
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21. *Ibid*.
22. *Joint Vision 2010*, 20-21.
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Richard A. Hardemon

General Logistics Paradigm: A Study of the Logistics of Alexander, Napoleon, and Sherman

Alexander the Great

Alexander the Great is rumored to have wept upon the conclusion of his conquests because there were no longer any nations to conquer. To a large degree, it is true that at his height of power, Alexander was the ruler of the known world. The tales of his conquest take on a mythical grandeur in which he is located somewhere between a man and a god. "Alexander was in fact, a living myth, and unless we accept him as such we cannot begin to understand his history."[1]

Generalship and Military Professionalism

The almost superhuman view of Alexander is not a modern contrivance. In fact, throughout most of his life, Alexander was treated with godlike reverence.

> Led by a god they [the Macedonian Army] faced all dangers, and it was their faith in him as a supernatural world-hero, as much as his inborn genius for war, which made him not only the greatest of all the Great Captains, but which distinguishes him from all and each one of them.[2]

This unparalleled allegiance to Alexander coupled with his genius for integrating logistics concerns into every facet of his military theory, doctrine, strategy, tactics, and administration enabled the support of a world-conquering army.

Alexander did not rise through the ranks but inherited his position from his father, Philip. Likewise he inherited a formidable fighting force without equal in the ancient world. Alexander's *professional education* was enviable, to say the least. He received instruction in strategy and tactics from his father and was privately tutored by Aristotle. The negative legacy of Philip and Aristotle's tutelage was their incredible hatred of the Persians, referred to by both Philip and Aristotle as the barbarians.

General Logistics Paradigm: A Study of the Logistics of Alexander, Napoleon, and Sherman

To a large degree, logistics concerns shaped Alexander's strategy and tactics. From the time of his initial defeat of Darius at Issus, through his campaign into Egypt, and his final defeat of Darius at Gaugamela (also known as the Battle of Arbela) Alexander displayed an acute awareness of the logistical requirements of his army.

However, Alexander seemed to rise above the hatred of his father and mentor and developed an attitude toward conquered peoples, even Persians, that was key in ensuring logistical support across the vast empire under his control.

Military Theory, Doctrine, Strategy, and Tactics

B. H. Liddell Hart characterized Alexander's logistics strategy as "direct and devoid of subtlety."[3] Moreover, to a large degree, logistics concerns shaped Alexander's strategy and tactics. From the time of his initial defeat of Darius at Issus, through his campaign into Egypt, and his final defeat of Darius at Gaugamela (also known as the Battle of Arbela) Alexander displayed an acute awareness of the logistical requirements of his army. Alexander considered the logistics implications of every aspect of the campaign, from the route he took to the allies he courted, in successfully moving the Macedonian army across the relatively barren desserts of Asia Minor.

Alexander began his move east from Macedonia, intent upon engaging the Persians at the Gracicus River. He had an estimated 10 days' worth of provisions for his army at Hellespont.[4] Ten days' provisions were ample, given Alexander's close proximity to ports along the Aegean Sea and the relative friendliness of the people of that region. Upon defeating the Persians at the Gracicus River, Alexander then marched on Sardis. It was on his march to Sardis that he encountered his first great logistics challenge. The direct route to Sardis was across mountainous terrain. However, Alexander elected to take a more circuitous route, moving back toward the coastline rather than southward to Sardis. This move was indicative of his exceptional grasp of logistics requirements and their direct influence upon the fighting capability of his army. Had he chosen the more direct route, not only would the terrain have slowed his advance, but the greater strain of covering mountainous terrain would have increased the consumption of supplies by both his men and horses. In all likelihood, his supplies would have been exhausted prior to reaching Sardis, and his army would have been located in the mountainous region vice the coastal area with its ready access to supply ships. Alexander repeated this strategy of attacking the enemy then quickly returning to the coastal region for resupply throughout his campaign against the Persians. The two exceptions to this strategy were his move on Ancrya (modern day Ankara) and his expedition into Egypt.

Alexander achieved two major logistics objectives in his capture of Sardis. Sardis was the political and economic hub of the entire region, and by bringing it under his control and raiding its treasury, Alexander further increased the resources he could draw. Second, the defeat of Sardis cleared his path southward along the coast of the Aegean. He then *liberated* Ephesus, Caria, Lycia, and Pamphylia. Alexander limited the Persian fleet's ability to move and took away their access to these ports by bringing these coastal cities under his control. A secondary effect of controlling these cities was that Alexander deprived the enemy fleet of a valued manpower resource. The Persians had been recruiting heavily from this area.[5] Alexander

continued his coastal movement through Lycia and Pamphylia. While passing through this fertile region Alexander again illustrated his ability to integrate logistics requirements with the gamut of additional concerns facing the leader of a large force. Although the region was fertile and presented an excellent source of resupply for his army, he was well aware the effect mountainous terrain had on the consumption of supplies. Additionally, it was now winter. He chose to grant leave to newlywed members of his army. This act of altruism was, in fact, a brilliant means of reducing the army's consumption of stores, in addition to significantly improving morale. Though it seems unusual to grant leave in the midst of a campaign, Alexander was sensitive to the limits to which this region could support his army, and he did not intend to march on until the end of winter.[6]

Throughout his campaign, Alexander left garrisons of forces at key locations along his route. This practice had three major purposes: it ensured the allegiance of the city was secure, it allowed the city to serve as a depot for the storage of supplies, and it protected his lines of communication. In some instances, Alexander was able to send a small force ahead to secure a city's allegiance and support. His emissaries were able to secure logistics support and supplies, simply because the city's leaders desired to be in favor with Alexander.

Alexander's army remained throughout the winter and spring in the region around Pamphylia. He did not make his march to Ancyra until well into summer. The reason for the delay was purely logistical. He would be departing the coastline and heading inland. Given his doctrine of traveling light, his army would quickly exhaust its supplies and be forced to forage. Knowing that, Alexander began his march in late summer to ensure crops within the region between Pamphylia and Ancyra had an opportunity to both mature and be harvested, the latter being performed by the residents of the region, thus sparing his army that arduous task.[7]

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En route to Ancyra, the Macedonian army crossed a region best described as an utter wasteland. Given the lack of potable water in this region, Alexander made frequent use of advance depots. He established the depots forward of the main army, with supplies from the rear augmented with whatever else could be secured at the advanced location.

Upon securing Ancyra, Alexander successfully consolidated his position in Asia Minor. He then marched to Issus and once again was forced to rely heavily upon the advance garrisons he had established, in addition to securing supplies from the local population en route. To his advantage, the majority of the cities between Ancyra and Issus were quite unhappy with their subjugation under Persian rule and viewed Alexander's cause favorably. Issus was a coastal city, which enabled Alexander to move forces garrisoned in the rear on the Aegean Sea forward. The army he had partitioned prior to his march on Ancyra was now back in full force at Issus. The partitioning and regrouping of his army aptly illustrates his philosophy of carrying only what was needed and could be supported. This applied to not only his supplies but also his troops.

General Logistics Paradigm: A Study of the Logistics of Alexander, Napoleon, and Sherman

One of Alexander's logistics strengths, one for which he cannot wholly take credit, was the organization of his army.

Upon his defeat of Darius at Issus, Alexander departed from the direct conquest of Persia. He then turned southward through Phoenicia and eastward into Egypt. Although Phoenicia and Egypt were under Persian control, Alexander did not face serious opposition until his return to Asia Minor. Additionally, his logistics philosophy was consistent with his earlier actions along the coast of the Aegean Sea. His route in Egypt followed the coast of the Mediterranean Sea. The majority of the cities, especially those in Egypt, viewed Alexander as a liberator and not a conqueror and were, therefore, generous in their support of his army.

Upon his return to Asia Minor, Alexander again remained near the coast and its valuable seaports. The cities that he passed en route from Egypt were now directly under his control and represented an asset rather than a possible threat. His departure from the coast and march on Arbela was made through the fertile Tigris-Euphrates Valley. Though meeting the logistics needs of an army is no small task regardless of location, Alexander's march through the Tigris-Euphrates Valley was not marked by any significant logistics challenges.

Alexander's defeat of Darius at the Battle of Arbela marked the end of the Persian Empire and Darius as their king. Key to his defeat of Darius was his approach to Darius' main body at an angle and the rapid encirclement of Darius' forces by Alexander's left flank. Alexander's successful use of maneuver is directly attributable to his overarching philosophy of flexibility and mobility, a philosophy integrated into and facilitated by his logistics practices.

Administration and Technology

One of Alexander's logistics strengths, one for which he cannot wholly take credit, was the organization of his army. "Alexander had as a legacy a model instrument—the army which Philip developed."[8] Key to Alexander's combat superiority and logistics prowess was his staff. In addition to the traditional second in command, called the Secretariat, Alexander had Keepers of the Diary, Keepers of the King's Plans, Surveyors and Official Historians. In addition to the more traditional staff functions, he also kept a large number of specialists and scientists on his staff. This wealth of expertise, both operational and logistical, he kept close at hand and without reservation solicited their counsel. Alexander's use of his staff of experts made his army formidable, not only in terms of its ability to execute combat operations but also in terms of its ability to plan and support combat operations.

Under Philip's direction, the Macedonian Army also underwent a significant change in the manner in which troops and provisions were transported. Philip outlawed the use of wagons in the Macedonian Army. This single act gave the Macedonian Army far greater speed and flexibility than any of their contemporaries. Philip's philosophy was expanded by Alexander, who limited the number of followers, civilians who tracked behind an army providing a gamut of services. Alexander only used horses, camels, and mules because of their greater speed and endurance over traditional pack animals such as oxen and donkeys.[9] The speed

and flexibility of the Macedonian Army proved to be its greatest asset on many occasions.

Social, Political, and Economic Factors

Philip, through his victory at Chaeronea, had secured control over Thebes and Athens. He then founded the Corinthian league and, through it, unified Greece. His next and ultimate goal was to destroy the barbarians, the Persians. His plans, however, were cut short with his assassination. Alexander was then left with the goal of conquering the Persians and, in doing so, laying claim to the known world. Despite his father's outright hatred of the Persians and the unbridled hatred of the Persians by Aristotle, his mentor, Alexander took a decidedly different view of his enemy. Alexander, too, saw the necessity of engaging and conquering the Persians. However, his purpose was well apart from the destruction of the barbarians. Under Philip, Greece had been unified, "and though he might have avenged Greece upon Persia, he [Philip] was not the man to carry the idea of *homonia* (unity in concord) into the world empire of his day … this supremely greater task was destined for his son."[10] Alexander's philosophy was not one of revenge and destructive conquest but one of control and ownership. When brought under Alexander's control, either through defeat, or in many cases by self-capitulation, a conquered city was left with a measurable level of autonomy.

His method throughout his reign was always the same. He separated civil administration from military control. The first he handed over to the representative of the conquered people, the second he placed in the hands of one of his chosen Macedonians.[11]

The speed and flexibility of the Macedonian Army proved to be its greatest asset on many occasions.

Alexander's goal was not for *homonia* just among Greeks but among all men, including Persians. In addition to the obvious political benefits this policy held, it provided substantial military logistics benefits. Although not completely free to choose whether or not to lend support to Alexander, conquered peoples, on the whole, favored life under Alexander's rule to that under some other conqueror and were generally supportive. On the off chance the *carrot* of semiautonomous rule did not persuade the conquered people, Alexander still had the *stick* of garrisoned troops left behind to oversee military affairs.

Napoleon Bonaparte

Napoleon is widely regarded as one of the premier generals of all time. He brought about numerous reforms in the way in which wars are fought and the very structure and composition of the fighting forces engaged in combat. Napoleon embodied the idea of the professional military leader, not gaining his position through political or familial connections, but earning it by distinguishing himself in combat. Although the focus of this study is on the logistics aspect of Napoleon's 1812 march upon Moscow, it first seems appropriate to recognize Napoleon for what he was, one of the greatest military leaders of all time.

General Logistics Paradigm: A Study of the Logistics of Alexander, Napoleon, and Sherman

A major drawback to Napoleon's superior generalship and professionalism during the planning of the Russian campaign was his overpowering need to be involved in every aspect. An even greater problem than this, however, was his tendency to make decisions without consulting with his key leaders.

Generalship and Military Professionalism

A major drawback to Napoleon's superior generalship and professionalism during the planning of the Russian campaign was his overpowering need to be involved in every aspect. An even greater problem than this, however, was his tendency to make decisions without consulting with his key leaders. There is a consensus among the accounts describing Napoleon's preparation for the Russian campaign that there were severe oversights regarding the logistic requirements of his army.

Although the planning for the Russian campaign was performed over the span of 2 years and showed some aspects of logistics consideration, it is clear Napoleon did not fully understand the logistical challenges he would face.[12] His misunderstanding, coupled with his reluctance to share information, had an obvious impact upon the soundness of the logistics aspects of his plan. His reluctance to seek the counsel of others was as much a function of "delusion and irrationality clouding his powerful mind" as the lack of any competent advisor. Just prior to the invasion of Russia, "there were few men left in the imperial entourage with sufficient integrity to speak their true minds," and "for the main part, Napoleon was now surrounded by claquers and sycophants."[13] Whether acting out of ego or necessity, Napoleon planned the Russian campaign, to a large extent, entirely on his own. Operating in a vacuum led to numerous logistics problems in terms of military theory, doctrine, strategy, tactics, administration, and technology.

Military Theory, Doctrine, Strategy, and Tactics

Throughout the planning and execution of the campaign into Russia, Napoleon committed numerous errors in terms of strategic focus and tactics, which directly affected the ability of his logistics system to support sustained operations. One of his greatest oversights was his doctrinal belief he could conduct a war on two fronts. When he began the invasion of Russia in 1812, Napoleon's forces were still actively engaged in a peninsular war with the Spanish. Though it is unclear as to his exact reasoning, Napoleon chose not to regard his commitment to the war in Spain. It seems he preferred to have the British involved on the side of the enemy in Spain rather than being involved in some other less convenient sector of Europe. Regardless of Napoleon's exact reasoning, the net negative effect of the Spanish War was the loss of 50,000 French soldiers per year and the consumption of an untold amount of the materials of war that could have been used in the Russian campaign.[14]

Though Napoleon did show some consideration for logistics, he viewed these requirements in a static sense. He failed to factor in the possibility that the support he anticipated would not be available. Similarly, he did not consider the possibility that the enemy he wanted to destroy would not engage him.

Napoleon's strategy did recognize the materiel challenges to be faced by any force marching on Moscow. The date for the start of the invasion, 23 June, was largely chosen for logistics reasons.[15] Napoleon thought the crops in Russia would be sufficiently developed and provide adequate forage for the thousands of horses upon

which he relied for transportation and as weapons of war. He also had the horses bear a larger-than-traditional load in an attempt to ensure an adequate supply of food for both man and beast. Unfortunately, the addition of the extra loads increased the horses' consumption of food, in essence negating or worsening the effect of the additional provisions. In very short order after crossing the Niemen River, Napoleon would see his fleet of horses cut down by a third because of an outbreak of colic, the relative lack of edible forage (on which he was counting), and incredibly hot weather. The loss of those horses had a cascading effect. Men who had been mounted were now forced to advance on foot, and horses were diverted from other details to fill vacancies in horse-drawn artillery teams. The net effect was to distribute the transportation and logistics burden over an ever-decreasing population of beasts of burden. The burden increased with the onset of heavy rains, which turned the Russian roads into impassable bogs. Throughout the campaign, the ever-dwindling supply of horses and the ever-worsening weather contributed to the complete destruction of Napoleon's ability to provide for his forces.[16]

The greatest strain on Napoleon's logistics system proved to be the Russian unwillingness to engage in battle. From the start of the campaign, the Russian forces were quite content in withdrawing and forcing Napoleon to pursue them. To compound this, they would also burn their own cities prior to abandoning them. Thus, the farther Napoleon marched into Russia, the farther he marched into a virtual wasteland. The Russians rarely left behind anything of use. Upon reaching his strategic goal of Moscow, Napoleon found it deserted and generally devoid of any useful supplies. The Russians, after fighting a pitched battle on the outskirts of the city and seeing the city would fall, simply deserted it during the night. The net effect of Napoleon's march on Moscow was that his army, some 250,000 strong when it crossed the Niemen, was reduced to 130,000 because of the lack of supplies, disease, and Russian hit-and-run attacks on Napoleon's rear. The Russian Army, which was outnumbered two to one when Napoleon crossed the Niemen, was now approximately equal in size to his army. Further, the Russian army, in spite of all its retreats, had stubbornly hung on to its artillery and enjoyed a slight numerical advantage over Napoleon's heavy guns. Upon reaching the strategic goal of Moscow, Napoleon was no closer to defeating the Russians than when he began, and he was now in the midst of a vast wasteland, several hundred miles from his stores of supplies in Warsaw.

In search of both victory and supplies to sustain his army, Napoleon marched on to Kaluga. It was en route to Kaluga that he obtained what he so desperately wanted—battle with the Russians. General Kutuzov made his stand at Maloyaroslavetz, a village on the road from Moscow to Kaluga. Although Napoleon was able to remove Kutzov's forces from Maloyaroslavetz, it came at the cost of 4,000 French troops. Worse yet, Kutuzov's forces still controlled the road to Kaluga. It was at this point that Napoleon began his retreat from Russia. Without losing a battle, he had lost the war.

The net effect was to distribute the transportation and logistics burden over an ever-decreasing population of beasts of burden. The burden increased with the onset of heavy rains, which turned the Russian roads into impassable bogs. Throughout the campaign, the ever-dwindling supply of horses and the ever-worsening weather contributed to the complete destruction of Napoleon's ability to provide for his forces.

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The administrative weakness of Napoleon's army was directly attributable to his style of leadership. Although Napoleon's influence had garnered great success in the past, he made the tragic flaw of assuming what worked in previous situations would work again, despite the dramatic difference the Russian campaign represented from his previous conquests.

It was now October, and 200 miles lay between Napoleon and his nearest supply depot, Smolensk. The depot at Smolensk was established on the march across Russia from Poland. Napoleon had charged the garrison commander to secure stores while the main body of Napoleon's army pressed onward to Moscow. Napoleon anticipated that upon the conclusion of the grueling 2-week march from Maloyaroslavetz to Smolensk he would be able to halt there and regroup. There were, however, three tragic flaws with this plan. The Russians were now attacking Napoleon's rear with great vigor. The garrison commander at Smolensk had precious few supplies at the onset of establishing the depot and, being surrounded by a virtual wasteland, had failed to secure any stores of adequate quantity. The weather was steadily deteriorating.

The strain on the weakened transport system was growing. All along the way, the men were discarding the bulkier and less valuable items among their loot. Rations were limited. Horseflesh began once more to be cooked at the evening campfires. Snow began to fall. And on the night of 5 November, the cold came.

No longer were the retreating troops faced with merely the unpleasant chill of frost. This was a cold that could not be held off by the upturned collars of their greatcoats. It could not be pushed aside by stamping in the snow or by holding cupped hands against ears and cheeks. This cold was so terrible that frozen feet, followed by frozen death, came upon men who had done nothing more than momentarily step into the ankle-deep water of some frozen roadside puddle on which a heavy artillery wheel, a moment before, had broken the ice.[17]

Upon his arrival at Smolensk, Napoleon realized his folly. There were no adequate stores at Smolensk, and he must keep moving, or his army would be lost. Throughout the retreat, the Russian Army dogged Napoleon's heels, at times separating the rear guard from his main body and inflicting even heavier casualties. When Napoleon finally returned from the Russian campaign, his army, once numbering 250,000, reported 8,800 men fit for duty.

Administration and Technology

The administrative weakness of Napoleon's army was directly attributable to his style of leadership. Although Napoleon's influence had garnered great success in the past, he made the tragic flaw of assuming what worked in previous situations would work again, despite the dramatic difference the Russian campaign represented from his previous conquests. Most important, Napoleon's army was larger than it had ever been, and the campaign was spread over the vast expanse of the Russian countryside.

The problems of time and distance were to prove too great for the capacity of a single mortal, even when that man was Napoleon. Napoleon's whole idea of warfare was based upon personal supervision of all parts of his army.[18]

His philosophy of direct supervision had proven difficult for him to execute over armies of smaller size that operated over a far more confined area. This philosophy proved impossible during the Russian campaign. Napoleon's inability to oversee his subordinates' preparation and execution of his planning led to significant

shortfalls in readiness and synchronization of effort. The army's reliance upon guidance from the highest levels led to poor preparation and logistics support.

Technologically, Napoleon's army was the model of modern arms for the time. However, technological superiority in this case did not ensure battlefield superiority. Specifically, Napoleon's heavy guns required multiple horse teams. The horses in turn required provisions of their own. The only means of replenishing a lost horse was to obtain it from another function within the army. The net result, as mentioned earlier, was the logistics burden continually being spread over a decreasing number of pack animals. Furthermore, Napoleon's wagons were well suited for the relatively passable roads of western Europe but were woefully inadequate in the boggy mire of the Russian countryside. The combined net effect was a technologically advanced force incapable of getting to the battle in force and forced to consume itself in order to keep pursuing an enemy not committed to full engagement.

Social, Political, and Economic Factors

Leading up to Napoleon's invasion of Russia, Tsar Alexander was able to make peace with Turkey, sign a treaty of alliance with Great Britain, and court the favor of Crown Prince Bernadotte of Sweden. The collective effect of this diplomatic maneuvering was that Russia "was able to clear her hands of all outstanding commitments and proved notably successful in her search for new allies."[19] Although Napoleon made similar political attempts to garner support, the vast majority of his support was obtained by force. The Russians were fighting on their own soil, which provided many logistical advantages. Their supplies had shorter distances to travel, and their personnel were well equipped to handle the severe weather. Tsar Alexander eerily predicted the results of the Moscow campaign in a conversation with Armand de Caulaincourt, then Ambassador to St Petersburg.

> If the Emperor Napoleon decides to make war, it is possible, even probable, that we shall be defeated, assuming that we fight. But that will not mean that he can dictate peace. The Spaniards have frequently been defeated; and they are not beaten, nor have they surrendered. Moreover, they are not so far away from Paris as we are, and have neither our climate nor our resources to help them. We shall take no risks. We have plenty of space; and our standing army is well organized. Your Frenchman is brave, but long sufferings and a hard climate wear down his resistance. Our climate, our winter, will fight on our side.[20]

Logistics problems played the pivotal role in Napoleon's failed campaign into Russia. Inadequate transportation systems, reliance upon single sources of replenishment, and improper provisioning for extremes in climate reduced the greatest army of the time, some 250,000 men strong, to a feeble force of 8,800 survivors. Until his retreat, Napoleon had not lost a battle, but he did lose the war.

Logistics problems played the pivotal role in Napoleon's failed campaign into Russia. Inadequate transportation systems, reliance upon single sources of replenishment, and improper provisioning for extremes in climate reduced the greatest army of the time, some 250,000 men strong, to a feeble force of 8,800 survivors.

William Tecumseh Sherman

The concept of generalship, a person's ability to be a general, cannot be viewed simply in terms of his conduct and influence upon his surroundings. His surroundings

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Sherman was far more forgiving of tactical errors than errors regarding logistics planning. He believed tactical errors often stem from the enemy's resistance and counteractions, which are the most incalculable factors in war, but a failure to adequately prepare was intolerable.

must also be evaluated. The environment in which the general commands has a great deal to do with his success and, in turn, will clearly influence the overall perception of his generalship. An analysis of William Tecumseh Sherman's environment leading up to and during the march on Atlanta provides unique insight into his generalship and military professionalism and how these threads of continuity both influenced and were influenced by his logistics practices.

Generalship and Military Professionalism

Ulysses S. Grant's appointment as Lieutenant General, Commanding the Armies of the United States in 1864, served to solidify unity, not only in terms of command but also in sense of purpose. Grant was the field general under whose leadership Sherman led the armies of the West into the heart of the Confederacy. Sherman's success can, in large part, be attributed to the autonomy with which he was allowed to operate. This autonomy was brought about as much because of Grant's trust in him as because of his geographic separation from Grant. Grant, in his written direction to Sherman, illustrates his belief in outlining what needs to be done, not how to do it. "I do not propose to lay down for you a plan of campaign, but simply to lay down the work it is desirable to have done, and leave you free to execute it in your own way."[21]

This concept of centralized control and decentralized command was especially useful given Sherman's nature as a man of action. His conduct during the preparation for and subsequent march on Atlanta is distinguished by quick and decisive action. His focus was first on the end goal, then on achieving it. In terms of logistics support, Sherman clearly identified his logistics requirements, then obtained the necessary means to meet them. Sherman was not prone to micromanagement. He simply expressed his requirements, established a completion date, and then ensured adequate motivation for completing the task. An excellent example of Sherman's leadership style, as it specifically relates to logistics, was the case in which a subordinate was not providing adequate transportation support. Sherman informed the officer that if he did not supply his army and keep it supplied "We'll eat your mules up." Sherman was far more forgiving of tactical errors than errors regarding logistics planning. He believed tactical errors often "stem from the enemy's resistance and counteractions, which are the most incalculable factors in war," but a failure to adequately prepare was intolerable. Sherman believed "by due foresight, preparation and initiative, material obstacles can always be overcome."[22]

Sherman enjoyed the benefit of the best military education available in the United States at the time. He was a graduate of the United States Military Academy. Despite not holding any cadet positions of authority while at West Point, he graduated near the top of his class, number six in the class of 1840.[23] The military education he received at West Point proved valuable because it provided a sound background upon which to build military command experience and was the same background the majority of the military leaders of the time had. Grant, Lee, Jackson, and numerous other Northern and Southern generals came from the same school of

thought, West Point. The classical approach to education at West Point undoubtedly exposed Sherman to the histories of great generals and campaigns of the past. It is then not surprising that there are significant similarities between Sherman's campaign into the heart of the South and Alexander's campaign against Darius.

Military Theory, Doctrine, Strategy, and Tactics

Sherman, in his memoirs, makes two points clear regarding his planning for the campaign on Atlanta: adequate supplies and maneuverability were key to the success. "The great question of the campaign was one of supplies."[24] Sherman was well aware of the relative length and vulnerability of his supply chain and took many creative steps to ensure he was provided adequate support.

Sherman was adamant about ensuring the highest maneuverability, while still maintaining adequate support.

> I made the strictest possible orders in relation to wagons and all species of encumbrances and impedimenta whatever. Each officer and soldier was required to carry on his horse or person food and clothing enough for five days.[25]

Sherman gave strict orders regarding the number of wagons and ambulances each regiment was allowed in addition to banning the use of tents by his army. The ultimate goal of Sherman was to strike a balance between maneuver and support. Sherman required each soldier to carry sufficient supplies for 5 days, yet he relieved units of the burden of carrying *nonessential items* such as tents, excess wagons, and ambulances. Sherman's key focus during the planning of the Atlanta campaign was to make his "troops as mobile as possible."[26]

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Sherman was well aware of the possibility of not receiving adequate support despite the many actions he had taken in preparation for the Atlanta campaign—the increased buildup of supplies at the front, commandeering of the railroads, and strict limitations he placed upon his army. Sherman bluntly informed General Grant of his anticipated course of action should his supply system fail to support him.

> Georgia has a million of inhabitants. If they live, we should not starve. If the enemy interrupt our communications, I will be absolved from all obligations to subsist on our own resources and will be perfectly justified in taking whatever and wherever we can find.[27]

Sherman's strategy and tactics in terms of logistics were then clear: a highly mobile force that would rely upon significant logistics support from the rear; whenever this support was interrupted, whatever was required would be taken from the local inhabitants. The plan of taking what was required from the local population further supported Sherman's overarching doctrine of bringing the horror of war to the people of the South.[28]

From the onset of the campaign into Atlanta, Sherman's strategy emphasized maneuver and focused on logistics. Specifically, Sherman's desire was to feign an attack on the Confederate forces at Dalton while engaging in a rear action to bar the retreat of the Confederate forces farther south to Resaca. If the Confederate forces were allowed to retreat south to Resaca, Sherman not only would face the burden of

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The Civil War arguably was the first modern war, especially when considering war in terms of the American experience.

being farther from his main supply depot but also be driving the Confederates closer to theirs.

Unfortunately for Sherman, his plans for a rear action were not completely carried out. Due to a lack of initiative on the part of one of his subordinate commanders, Sherman's army failed to attack the rear decisively, and Sherman's attempt to execute a rear action failed to reach complete fruition. However, Sherman's actions did have both a negative and positive result. The Confederate forces were drawn away from their fortified position in Dalton to a far less favorable position with their retreat through Resaca across the Oostenaula River.

> It was nevertheless a brilliant achievement to have maneuvered so renowned a master of defense [General Johnston, Confederate commander at Dalton] out of two strong positions against his will and his orders.[29]

The negative result of the Confederate retreat was that Sherman had missed a golden opportunity to trap Johnston's army and attack it from the rear. "Sherman had a lengthening line of communication [and supply], Johnston a shortening and less exposed one."[30]

Throughout the remainder of Sherman's march to Atlanta, he was able to effectively employ maneuver to force Johnston backward while continually supplying his troops from the rear. Essential in the resupply effort was a trailing echelon of 2,000 troops under the command of Colonel Wright, a civil engineer, whose expertise in the repair of enemy-damaged railways enabled virtually uninterrupted resupply to the forward lines beyond Resaca. "Time after time, Sherman's greater army outflanked Johnston's lesser forces, compelling their withdrawal."[31] Sherman eventually won the Battle of Atlanta and captured the city.

Administration and Technology

The Civil War arguably was the first modern war, especially when considering war in terms of the American experience. The North, in particular, was a highly industrialized region capable of producing a variety of both durable and consumer goods. One key necessity of industrialization is the need for rapid, reliable transportation. In the late 1860s, the railroad developed as an indispensable mode of transportation for both military and civil concerns. Sherman, well aware of its importance, made the acquisition and maintenance of rail transportation, while denying it to the enemy, a priority.[32]

Chattanooga, the starting point for Sherman's advance on Atlanta, lay 151 miles from his supply depot at Nashville, which in turn was 185 miles from his main source of supply in Louisville. Given the significant length of Sherman's lines of supply, it was of paramount importance that he secure adequate transportation for supplies and reserves. His first step in ensuring a reliable line of supply was to acquire supreme control of the railroads. Previously, the railroads had been controlled by "the departmental commanders, with consequent friction and uneven distribution of supplies."[33] Sherman, much like Grant had done for the entire Union Army, unified his control over this critical resource. Sherman then decentralized execution while

maintaining overall control. His philosophy of overarching control and decentralized execution of railroad operations resulted in two largely beneficial effects. He was able to oversee the flow of supplies to the front without directly involving himself in the *ins and outs* of rail operation, and he eliminated the bickering and supply imbalance between subordinate commands. A secondary effect of Sherman's control of the railroads was his ability to weigh in with the authority of his office should any problems arise.

He further ensured the availability and proper use of railroads by banning civil traffic. Still not satisfied, despite the fact his daily delivery of stores to the front had doubled, Sherman directed that cars and locomotives from other locations be diverted to the Chattanooga line. The decision to ban civil traffic and commandeer additional cars was not an attempt to simply bring a valuable resource directly under his control. He had a clear level of support in terms of rail shipments, 130 ten-ton car loads per day, he felt must be met, and taking control of the railroads seemed the logical way to do it.[34]

Sherman also displayed his penchant for centralized control and decentralized execution in both his mode of operation and his army's organization. An excellent illustration was the composition of his staff. His staff included functional experts in artillery, engineering, ordnance, logistics (actually called Chief Quartermaster and Commissary) and medicine. In addition to the functional representatives, Sherman's staff had three inspectors general and three aides-de-camp. Conspicuously absent from his staff was the administrative function. He advocated that clerical work in the field be kept to a minimum and used permanent clerical offices in the rear for daily correspondence. The composition of his staff facilitated the scheme of centralized control by using the staff in a controlling capacity while still leaving the execution to the lower echelons.

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Social, Political, and Economic Factors

The political motives behind Sherman's campaign were clear: to bring the war and all its horror to the heartland of the South. "Sherman was eager to teach the people of the South a lesson in the horrors of war, believing that a harsh war would ensure a lasting peace."[35] Sherman further believed he was justified in his laying claim to any and all stores before him, shaking off the "old West Point notion that pillage was a capital crime."[36]

Analysis

Though it can be maintained that the two largely successful campaigns of Alexander and Sherman had many similarities among policies and practices, it cannot further be assumed that there then exists some exacting set of rules or practices shared by the two that will always guarantee success if employed. This study does not attempt to develop a listing of the key logistics principles that will guarantee success but, rather, establishes a logistics paradigm intended to be a guide or a starting point from which current and future military leaders can develop their

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The campaigns of Alexander and Sherman illustrate the good logistics practices, while Napoleon's campaign into Russia provides the lessons learned.

own policies and practices. By analyzing the commonalities among successful campaigns and integrating those with the lessons learned from not-so-successful campaigns, a logistics paradigm is developed that is based upon practices proven to be valid in antiquity, which forms a starting point from which leaders can tailor their own practices to fit their specific situations. The campaigns of Alexander and Sherman illustrate the good logistics practices, while Napoleon's campaign into Russia provides the lessons learned. The framework for analyzing the commonalities and lessons learned is based upon the threads of continuity approach.

Generalship and Military Professionalism

In terms of formal military education and background, backgrounds of Alexander and Sherman are dramatically different than that of Napoleon. The former represent the aristocratic general, while the latter represents the journeyman solider. In no way does that mean Napoleon was a lesser general. He is arguably one of the greatest generals of all time. What is meant by the distinction between aristocratic and journeyman is that both Alexander and Sherman were taught to be generals and leaders of men, while Napoleon was first taught to be a soldier and, through aptitude and hard work, rose to his position as general. Both Sherman and Alexander received superior education and military training compared to their contemporaries. Alexander's private tutor was Aristotle, and he was taught by his father, Philip, from an early age how to be a general. Sherman attended the United States Military Academy and was commissioned as a second lieutenant, with the focus of the United States Military Academy on teaching men to be leaders and, ultimately, generals. Napoleon, though a graduate of l'Ecole Militaire, did not have the formal military education of Sherman. L'Ecole Militaire during Napoleon's time was not "particularly distinguished for the attention it paid to the proper preparation of its young aspirants for commissions."[37] Similarly, given Napoleon's middle-class upbringing, he was not afforded the tutelage of a great thinker, and his father was not a great general.

Though no direct correlation can be made about the military education received by Alexander, Napoleon, and Sherman and their general logistics practices during the campaigns under study, their backgrounds provide insight into the disposition and character of these generals. It can clearly be seen that by working his way up from his middle-class beginning through the ranks as a junior artillery officer, Napoleon developed a significant sense of self-reliance and, as was the case during the planning for the invasion of Russia, a need to be involved in every aspect of the operation down to the minutiae. Conversely, both Sherman and Alexander consistently maintained supervisory oversight of their armies while leaving the precise execution of daily operations to their functional experts.

Military Theory, Doctrine, Strategy, and Tactics

Military theory, doctrine, strategy, and tactics, for the purpose of this analysis, are focused at the operational level and can be viewed in general terms as to how each

general conducted the campaign. Each of the three campaigns represents dramatic differences in how the conduct of war influences or is influenced by logistics. Alexander's conduct of his campaign was greatly influenced by logistics concerns. Napoleon's logistics practices were greatly influenced by how he intended to conduct his campaign. Unfortunately for Napoleon, how he thought he was going to conduct the campaign was not how he ended up conducting it, and his logistics system proved horribly inadequate. Sherman's conduct of his campaign was influenced by logistics concerns and influenced his logistics practices.

Alexander's foremost concern was the adequate provisioning of his army, as is evident in his route through Asia Minor. Though the defeat of the Persians was the ultimate military goal of his conquest up to the Battle of Arbela, clearly that could not be accomplished without first addressing the logistics needs of his army. Throughout his campaign, Alexander employed three main techniques to ensure adequate provisioning. First, he stayed as close to the coast as possible. His proximity to the coast facilitated easy access to his fleet of supply ships while denying port access to his enemy. Second, he modified the size of his army (flexible sizing) to suit the environment he was facing. An excellent example of this was when Alexander, faced with the onset of winter after passing through the region around Pamphylia, granted leave for all newlywed members of his army. The granting of leave greatly decreased the number of troops he had to supply and undoubtedly had the additional benefit of increasing morale. Finally, when he marched inland, he took great pains to ensure advance logistics support. He sent military envoys ahead with the charter to inform local officials of his approach. The message was clear; surrender yourselves and your property or be destroyed. As was often the case, support was granted without the use of force.

Napoleon's hubris was that he failed to fully understand the environment in which he was to conduct war and, therefore, developed a logistics system that was woefully mismatched for that environment.

Napoleon's *hubris* was that he failed to fully understand the environment in which he was to conduct war and, therefore, developed a logistics system that was woefully mismatched for that environment. The most popular example was the inadequacy of Napoleon's wagons to effectively negotiate the rough Russian countryside. However, a closer examination indicates the problem was just as much about what he carried and how he carried it as what it was carried in.

Though Napoleon had planned the start of the invasion to coincide with the harvest in western Russia, the availability of crops proved inadequate to support the thousands of horses he relied upon for transportation and as weapons of war. The lack of fodder, combined with an outbreak of colic, decimated his fleet of horses and had the cascading effect of spreading the burden over an ever-decreasing number of horses, which in turn increased their consumption of supplies. Worse yet, as the number of horses decreased, horses had to be shifted from pack details to pulling artillery. The shortage of pack horses meant more was being carried by men, increasing their consumption and reducing their mobility.

Napoleon's greatest misunderstanding was how the Russians would respond to his advance. The Russian willingness to trade land for time proved to be Napoleon's

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Sherman's logistics policies and practices influenced and were influenced by how he conducted his campaign. Sherman was well aware of the logistics strain and the vulnerability of his lines of supply as he advanced toward Atlanta. He took unusual measures to bolster his lines of supply. From the planning stages through the execution of the campaign, he maintained control of the railways.

undoing. As Napoleon pressed farther and farther into Russia, he traveled farther and farther away from his main supply reserves in Poland and farther into a vast wasteland. The Russians laid waste to anything of logistical value prior to retreating, leaving Napoleon with little to draw upon from the local population. The Russian *scorched earth* tactic, accompanied by constant attacks on Napoleon's lines of supply, deprived Napoleon of even the slightest relief. By the time Napoleon was able to engage the enemy face-to-face, his 2-to-1 superiority in numbers had vanished. With the onset of winter, he realized the war was lost, and in his desperate march back to Poland, he lost the bulk of his remaining troops.

Napoleon began the campaign with the anticipation of relying upon the available crops within the area to augment the provisions his army carried with them. Additionally, he intended to bring his superior numbers and firepower to bear against an enemy in an army-to-army confrontation for the control of the capital. Unfortunately, what he encountered was something far different. Had events gone as Napoleon expected, it could be argued that he well may have won in Russia. However, Napoleon's logistics plan and practices proved woefully inadequate in the end.

Sherman's logistics policies and practices influenced and were influenced by how he conducted his campaign. Sherman was well aware of the logistics strain and the vulnerability of his lines of supply as he advanced toward Atlanta. He took unusual measures to bolster his lines of supply. From the planning stages through the execution of the campaign, he maintained control of the railways. He diverted locomotives from other locations and aggressively repaired battle-damaged rail lines. His route southward followed the main rail line from Chattanooga to Atlanta. Clearly, in this instance, his conduct of war was influenced by logistics.

Sherman is noted for the destruction that he brought to the heart of the South. The destruction he inflicted was neither solely the result of pillaging for supplies nor the result of pure malice and wanton destruction but a combination of both. Sherman was clear from the onset of the campaign that one of his motives was to bring the war to the people of the South. He also considered himself completely justified in obtaining whatever he required from the local population. He believed if the Confederate forces impeded the flow of supplies to the front he was then perfectly justified in acquiring the supplies he needed from the local population. Whether it be the case that the Confederate forces significantly affected Sherman's supply lines or that he simply needed more supplies than he could provide for himself, before the onset of the campaign, he clearly established his intention to take what was needed from the local population. Sherman allowed his desire to bring the horror of the war to the people of the South, a key element in how he was to conduct this campaign, to influence his logistics practices.

Sherman and Alexander shared one key factor in their conduct of war: the logistics requirements they placed upon individuals during the planning stages of their respective campaigns. Both gave specific instructions aimed at lightening the load

of individuals and individual units under their commands. Interestingly, both Alexander and Sherman prohibited the use of tents. Alexander built upon Philip's requirements and minimized followers, while Sherman limited the number of wagons available to individual units. The ultimate end goal was to increase individual and unit mobility by limiting to the bare essentials what was carried. This is not to say that Napoleon did not take measures to increase mobility and in turn increase the army's ability to maneuver, but in the case of Alexander and Sherman, maneuver proved to be the deciding factor in the defeat of their enemy. Sherman was able to outflank Johnston's forces, and Alexander was able to attack Darius' forces at an angle and encircle them. Both victories resulted from the successful use of maneuver, which was directly attributable to their armies' ability to move quickly, a concept integrated into and facilitated by their logistics policies.

Administration and Technology

A key attribute shared by both Alexander's and Sherman's success, which proved to be a contributing factor to Napoleon's failure, was the use of their staffs. Both Alexander and Sherman had experienced and trusted military advisors to advise them on a multitude of functional areas. Though Napoleon also had a staff, his, to a large degree, was made up of *claquers and sycophants*.[38] It is unclear if the lack of sound advisors resulted in Napoleon's tendency to micromanage or if his management style made a staff position an overly unattractive billet for anyone except a sycophant. Regardless of the cause for his less than competent staff, its lack of competence left Napoleon with little choice but to rely upon his personal involvement in all aspects of the operation of his army.

A key attribute shared by both Alexander's and Sherman's success, which proved to be a contributing factor to Napoleon's failure, was the use of their staffs.

As discussed earlier, both Sherman and Alexander, to a large degree, dictated what was to be done but not how to do it. Such a philosophy is an excellent indicator of a high level of trust and respect for one's subordinates and indicates a capable and competent staff.

Each of the three armies represented the most technologically advanced fighting forces of their time. They differ, however, in how they adapted their technology to fit the situation at hand. Napoleon had state-of-the-art weaponry, especially artillery, yet he was unable to use it effectively because he could not transport it effectively. The wagons carrying his artillery were well suited for the well-maintained roads of Western Europe but were woefully inadequate in the impassable bogs of the Russian countryside. Alexander, on the other hand, purposefully did not use traditional pack animals, such as oxen and donkeys, but opted for animals with better endurance and speed, such as horses and camels. Alexander adapted his transportation technology to suit the situation. Sherman took complete control of the railways and ensured he had a viable repair activity prior to the start of the Atlanta campaign. He exploited available technology to his advantage while denying the enemy access to it. Similarly, Alexander made great use of naval resupply and, in doing so, denied the enemy similar access since he controlled the ports. Alexander's and Sherman's ability to adapt and apply logistics technology, specifically transportation

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Although each of the three campaigning forces interacted differently with local inhabitants, there is one common aspect that defined the interaction. In the case of the successful campaigns, the commander understood the environment he was to operate in, to include not only the tangible factors such as terrain but also the intangible factors such as the resolve and attitude of the people he intended to conquer.

technology, rather than their absolute technological superiority, proved valuable in the success of their campaigns.

Social, Political, and Economic Factors

To analyze the effect of social, political, and economic factors, this study examines the interaction between the campaign forces and the indigenous peoples and local environment. Although each of the three campaigning forces interacted differently with local inhabitants, there is one common aspect that defined the interaction. In the case of the successful campaigns, the commander understood the environment he was to operate in, to include not only the tangible factors such as terrain but also the intangible factors such as the resolve and attitude of the people he intended to conquer.

As discussed previously, Napoleon's failure to comprehend Russian resolve and willingness to sacrifice land for time was key in his defeat. In his statement to Armand de Caulaincourt, Tsar Alexander was quite clear about the Russian willingness to use the vastness of their frontier and the severity of their climate as key aspects in their defense. Apparently Napoleon failed to regard these comments or simply thought that even if the Russians did employ these tactics they would be of little impact. Napoleon was also willing to begin his offensive against Russia while still engaged in a war with Spain. He neglected to realize that a fundamental building block to alliances is a common enemy. Unfortunately for Napoleon, the fact that France was engaged in two wars made France far less attractive to any new prospective allies than Russia, who had settled all her other disputes. The net result was Russia was able to form alliances with Great Britain and Sweden and make peace with Turkey. Napoleon failed not only to comprehend the impact of the physical environment upon his logistics plan but also to recognize the political environment's effect upon his logistics plan. Russia had gained new allies and made peace with former enemies, which allowed her to focus on the entire military logistics capability toward a single foe. Unlike his Russian enemy, Napoleon was now actively engaged in fighting a war on two fronts, with the bulk of his allies being former conquered peoples whose support was tenuous at best.

Sherman understood well the environment he was to encounter during his campaign. One of his specific goals was to change the environment of the enemy citizens he encountered. Atlanta and the surrounding region represented a wealthy and pristine area of the South, particularly in terms of its exposure to the destruction of the Civil War. Sherman conducted his campaign "aimed at defeating the South psychologically as well as militarily."[39] He was dramatically successful in both aspects. Sherman not only successfully completed his campaign to capture Atlanta but also left a lasting mark on the consciousness of the enemy population he encountered. Sherman clearly understood his environment and made affecting that environment a key factor in his campaign.

Alexander, too, was well aware of the environment he was to encounter. He, however, took a decidedly different approach than Sherman. Alexander allowed

the conquered people to retain some measure of autonomy with regard to their own civil affairs. Additionally, the people he encountered often surrendered to Alexander without a fight and in some instances viewed him as a liberator from the oppressive rule of the Persians. The conquered peoples' view of Alexander is in stark contrast to how Napoleon and Sherman were viewed during their respective campaigns. Alexander's goal, too, was different from that of Napoleon or Sherman. Where Sherman explicitly wanted to make war on the people of the South and Napoleon wanted to conquer the people of Russia, Alexander, to a large extent, wanted to unify, under his rule, the people he conquered. This distinction between conquering and unification on the surface may seem subtle, but examination of how conquered people were treated by the two generals illustrates the dramatic difference between the two concepts. Alexander retained military control but, to a large extent, left the civilian population to continue their lives as they had done before. Napoleon, in contrast, retained control through the establishment of some puppet civil and military leadership. The net result was those under Alexander's rule, to a large extent, were unaffected by the shift in power, whereas former enemies under Napoleon's control were much the worse for the shift in power. Clearly, Alexander realized that if he was to accomplish his goal of *homonia* he would have to ensure the eventual and lasting support of the people. *Homonia* could not effectively be accomplished at the point of a spear. By understanding and integrating the political and social environment of the people he conquered, Alexander obtained their support, a factor that played a major role in his logistics practices during the campaign to defeat Darius.

The conquered peoples' view of Alexander is in stark contrast to how Napoleon and Sherman were viewed during their respective campaigns.

Conclusions

The conclusions set forth in this article result from an examination of the events surrounding the campaigns examined and an analysis of the commonalties among successful campaigns and lessons learned from the not-so-successful one. The logistics paradigm resulting from this analysis has four key principles. Each principle of logistics put forth by the analysis relies upon the use of demonstration by "revealing a necessary connection between the defining properties of the object being compared."[40] Key to the validity of the logistics principles, and in turn the entire paradigm, is the underlying assumptions specifically outlined with the explanation of the principles. The assumptions form the framework in which the application of the principles apply as per the demonstration.[41]

It can easily be seen the four principles of logistics offered by this article are not entirely new to anyone familiar with the study of war. In fact, in some form or another, each of these principles appears in several prominent historians' statements of principles of war and logistics. However, the method with which these principles can be applied distinguishes them from previous theory. The difference between the principles put forth in this article and other theories will be discussed, but the principles themselves must first be described.

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Centralized Control, Decentralized Execution

As described earlier, both Alexander and Sherman made extensive use of staffs of functional experts. Conversely, Napoleon, though possessing a staff of his own, tended to be involved down to the lowest operational levels. The logistics challenges Napoleon faced would prove too great for any one man to handle, even if that man was Napoleon.[42] Sherman and Alexander allowed their functional experts to manage the daily operations of their specific area of responsibility, and both generals weighed in with the authority of their office only when needed. Their management philosophies allowed them to focus on the overall management of their armies, while still staying close to the daily operations managed by their staffs.

Although these campaigns involved large armies and the necessity for centralized command and decentralized execution seems well founded, there is just as much applicability of this concept for smaller sized, more modern military units. Given the assumption that logistics concerns are a function of the complexity of the operation at hand, which is, in turn, a function of the people, equipment, and supplies being used, then the challenge of meeting basic logistics requirements has increased in proportion to the complexity of the fighting force. Though the size of the army or military unit may be quite different from that of Alexander, Napoleon, or Sherman in modern times, it is still quite complex. Complexity then implies the need for exacting expertise in numerous, specific fields integrated to support an overarching end goal or mission. In much the same manner that even a general as brilliant as Napoleon could not manage the wide gamut of logistics and nonlogistics issues he faced during the campaign into Russia, neither can a modern military leader expect to have adequate knowledge in the gamut of functional areas of responsibility. Though an extensive staff may be neither practical nor attainable, a leader should be willing and endeavor to consult the functional experts.

Key to the validity of centralized control-decentralized execution and its implied reliance upon functional experts is that such experts exist and are available. This assumption seems negligible, but the availability of a competent staff or group of advisors is quite rare in small military units. Of even greater concern is the lack of true functional experts. Though career broadening and the blurring of the lines between logistics specialties in the modern military does provide an increased pool of *trained* personnel from which to draw upon to fill logistics billets, it necessarily results in the reduction of true functional experts who have spent the bulk of their career learning their specialty and honing their skills to a superior level. The greatest challenge to the concept of centralized control and decentralized execution is the loss of true functional experts.

Flexibility

The need for flexibility seems to be an item of consensus among students of military history. Flexibility is analyzed in this article as the degree to which forces can adapt to their environment, specifically, how logistics policies and practices enable forces to quickly adapt to their environment. Both Alexander and Sherman made advance

orders to their armies specifically outlining what they could and could not bring with them, the ultimate goal being the most mobile force they could possibly have. Alexander and Sherman used maneuver as a key tactic in the defeat of their enemies. What is not so well documented, but equally important, is how their ability to move rapidly between battles further enhanced the capability of their armies. Napoleon, on the other hand, was unable to maneuver with any success and was forced to plod along the Russian countryside, enabling the enemy before him to retreat and lay waste to anything of value prior to his arrival. The flexibility to move and maneuver was clearly key in the success of Alexander and Sherman and was integrated into all aspects of their armies, to include their logistics planning and practices.

Additionally, this article examines flexibility not only in terms of an army's ability to respond to the physical aspects of the environment but also in the more intangible aspects of the environment. Napoleon very well may have been able to overcome the hardships he faced crossing the Russian countryside if he had an enemy to fight directly in battle. Ironically, it was the lack of an enemy that led to his eventual defeat. In taking Moscow, Napoleon fully expected the war to be won. When Napoleon marched into the capital largely unopposed, he was no closer to defeating the Russians than when he began his campaign. The Russians simply abandoned Moscow and, after Napoleon's arrival, set parts of the city ablaze. The intangible factor of Russian willingness to trade land for time proved to be the downfall of Napoleon's logistics plan. Though it cannot be said if his logistics plan would have adequately supported his troops had he been able to conduct the war as he had planned, it can be said that his logistics plan based upon the invasion of Russia and the ultimate capture of Moscow was not capable of sustaining his army in the protracted conflict into which he was lured.

Key to the validity of centralized control-decentralized execution and its implied reliance upon functional experts is that such experts exist and are available.

Flexibility is the key to the success of any organized unit, military or otherwise. If an organization cannot adapt to changes in the physical and intangible factors which encompass its environment, then it will become extinct. The challenge in developing, obtaining, or maintaining flexibility is that it, in some sense, presumes clairvoyance. Clearly, it is easy to identify factors that at present must be adapted to or overcome. It is an entirely a different matter to plan for factors—or contingencies— before they manifest themselves, the mark of true flexibility. The measure to which a unit can respond to unforeseen contingencies is the true measure of the unit's flexibility. Therefore, the principle of flexibility implies the assumption that measurable flexibility is the result of planning for immeasurable and unforeseeable contingencies. Additionally, every contingency that is planned for and not encountered is needlessly planned for. The paradox is there is no way to know with any surety which contingencies will arise and which will not. The lack of a spare tire is only problematic when a flat tire is encountered. Otherwise, the omission of a spare tire represents additional cargo space and possibly better gas mileage. Flexibility then is more an aspect of the art of logistics than the science of logistics. It is both logistically and economically not feasible to plan for every

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Both Alexander and Sherman not only properly applied the technology available to them but also integrated this technology into their logistics support practices.

possible contingency, but to the largest degree possible, logistics plans should be adaptable to the gamut of most likely contingencies. Quality planning and experienced logistics leadership can go a long way in the development of viable contingency plans. The major factor in ensuring flexibility, however, is not to attempt to analyze every possible contingency and then plan for it. In fact, this will result in excessive waste, and as pointed out earlier, those contingencies not encountered are needlessly planned for. The key is to develop a logistics plan that at its core is highly adaptive, meaning it requires the minimum possible support from external agencies. By having a highly adaptive logistics plan, the unit's reliance on its environment is minimized, allowing it to function unencumbered in a wide variety of environments, thus enhancing flexibility.

Proper Application of Technology

Both Alexander and Sherman not only properly applied the technology available to them but also integrated this technology into their logistics support practices. Alexander made use of nontraditional pack animals because they better fit the environment in which his army was operating. Additionally, Alexander made use of sealift whenever available. The capture of enemy ports and the coastal route Alexander followed illustrate how he integrated transportation technology into his overall strategy. His route and the ports he captured enabled him to exploit available shipping while preventing his enemy from doing the same. Similarly, the use of shipping enabled better and more rapid resupply, further enhancing his capability to execute his strategy. Sherman, prior to the march on Atlanta, was well aware of the critical role railroads would play in his preparation and execution of the campaign. He took the unprecedented step of bringing this critical asset under his control to ensure its proper use and application in support of his efforts. Furthermore, Sherman had the foresight to form and utilize a rail repair force of some 2,000 troops. The rail repair force enabled the quick repair of any damaged rail lines and resulted in the preservation of this valuable transportation technology.

It cannot be said, however, that technologic superiority necessarily equates to victory. Napoleon's force at the onset of the Moscow campaign represented the most technologically advanced force of its time. Additionally, it enjoyed numeric superiority over the Russian forces by whom it was ultimately defeated. The key in Napoleon's case was that he was unable to exploit his technological advantage, or in other words, he failed to properly apply the technology available to him. There are numerous instances throughout recent history in which a technologically superior force was defeated by a technologically inferior enemy, but those conflicts are not the focus of this article. In a broad sense, technology can be seen as a single tool. No matter how advanced the tool, if it is used improperly or if it is the wrong tool, it simply will not work.

For modern military leaders, the challenge to the proper use of technology is that in most instances leaders do not have the leeway to determine the technology they employ. This is most true in terms of the actual weapons a unit employs. The critical

assumption regarding the proper application of technology is that there is some choice regarding the technology that can be used. The greatest leeway, in terms of technologic choice, is in how the weapons of war, to include troops, are provided. It is true in this case the most technologically advanced method may not always be the best method. Though airlift in its own right might be the fastest mode of shipment, attempting to airlift an entire support package may result in a bottleneck and lengthy delays awaiting available air transport. The ultimate result may be the support package, had sealift been used, would have arrived earlier than by air due to sealift's ability to handle a larger capacity of freight. Similarly, the best way to provide potable water is to employ portable water purification units. However, this application of advanced technology is only of use if some source of water exists. This may not always be the case in extremely arid regions. The examples are numerous and further illustrate that superior technology is only of use if it is applied properly or can even be applied at all.

Understand the Environment

A major function of logistics is the neutralization of the effects of the environment. Clearly, it follows that to neutralize the effects of the environment the environment must be understood first. The paradox is the ability to completely understand the environment is beyond the capacity of any individual or group of individuals. This problem is further compounded by the fact that the environment can be defined in varied terms or at varied levels of precision. For example, the United States can be defined as the 50 states and all territories. An equally valid description is that the United States consists of all those individuals who consider themselves American. Furthermore, the United States can be defined in terms of longitude and latitude. The course of action offered by this article is that, given the environment is at best vaguely defined, the key to understanding the environment is to define as much as can be defined and then integrate control, flexibility, and technology in such a manner as to minimize the effect of any unforeseen factors in the environment. Therefore, the fourth logistics principle offered in this article is as much the integration of the previous three as it is an individual concept in its own right.

A major function of logistics is the neutralization of the effects of the environment.

The environment, though definable in multiple terms, does have basic characteristics of interest to military leaders. Though the physical aspects of the environment, terrain, size of the enemy force, and supply requirements, to name a few, tend to garner the bulk of a military leader's attention and accordingly are addressed by his strategy, tactics, and logistics plans, the intangible aspects of the environment are just as important. Napoleon had a fairly good grasp of the tangible environmental factors that he would encounter during his invasion into Russia. What he failed to consider was the intangible factors that dramatically altered the effect of the physical factors of the environment. The Russian willingness to trade land for time resulted in Napoleon's advancing farther into the interior of Russia without garnering a victory. The Russian willingness to surrender their capital without a major conflict resulted in Napoleon's having to press even farther into

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Napoleon's logistics plan was not developed to support a seek-and-destroy mission across the vastness of the barren Russian countryside. Had Napoleon understood Russian resolve—that is to say, understood the intangible aspects of the environment of a war with Russia and integrated proper control, flexibility, and technology into his logistics plans—the outcome of the Moscow campaign could have been dramatically different.

Russia in search of an enemy to defeat. These two intangible factors resulted in Napoleon's having to completely change his concept of how he was going to defeat the enemy. Furthermore, Napoleon's logistics plan was not developed to support a seek-and-destroy mission across the vastness of the barren Russian countryside. Had Napoleon understood Russian resolve—that is to say, understood the intangible aspects of the environment of a war with Russia and integrated proper control, flexibility, and technology into his logistics plans—the outcome of the Moscow campaign could have been dramatically different.

Alexander was attuned to the environment he encountered during his campaign against Darius. His goal of *homonia* for all people had no hope of being achieved unless he could bring the conquered peoples under his control. Alexander knew that he would not maintain lasting control if he relied upon military force alone to keep his newly acquired territories in line. He, therefore, allowed them a large measure of autonomy with regards to their own civil affairs. Interestingly, Alexander was viewed as a liberator in some of the areas that he conquered since life under Alexander was viewed as better than life under the rule of Darius. Alexander was able to exploit his understanding of the environment to gain support from the local population. He successfully integrated his control policies, flexibility, and technology into a plan that exploited the support of the local environment and could be adapted to any adverse factors that arose from the environment. Alexander would gladly accept support from the local population, but should they choose not to support him, he was more than capable of adapting and taking whatever he needed by force.

Sherman, too, was well attuned to the environment. In fact, one of his overarching goals was to affect the environment of the people he encountered. Sherman, from the planning stages of the Atlanta campaign, was clear in expressing his willingness to acquire whatever was needed from the local population if the need should arise. This would serve the twofold purpose of meeting his logistics requirements while further supporting his goal of bringing the war to the people of the South. Sherman, by understanding his environment, was able to integrate control polices, flexibility, and technology into his logistics plan, which not only limited the effect of adverse environmental factors but also promoted one of his ultimate goals.

Modern military leaders face an environment that is extremely complex and consistently changing. Major political events in recent history have significantly changed the political, social, and economic landscape of the world. The potential theaters of operations are now, more than any other time in history, more diverse and geographically separated. Given that, it is impossible to understand every possible environmental factor, both tangible and intangible, that may present a logistics challenge. However, by knowing as much as possible about the people, geography, and culture of many areas and developing logistics plans and practices that integrate proper control, flexibility, and technology, the effect of unforeseen and adverse environmental factors can be minimized.

Other Views on Logistics Principles

The four logistics principles put forth by this article—Centralized Control/ Decentralized Execution, Flexibility, Proper Application of Technology, and Understanding the Environment—can be found in some form or another in other research. However, it is how this article applies these principles that is quite different from previous research. These principles are not simply a listing of specific *dos* and *don'ts*, they are intended to form a paradigm or framework of thought from which military leaders can draw to develop their own policies and practices. The biggest failing of a list of *dos* and *don'ts* is that it cannot hope to fit every possible situation and, in fact, may be the worst possible course of action for a given environment or situation. The paradigm consisting of the four principles of logistics is intended to guide thought, not specify actions. It facilitates creativity while offering a bounded framework for the development of executable logistics plans. A comparison of Huston's and Thompson's principles of logistics with the four principles of logistics outlined in this article serves to further illustrate the applicability and adaptability of these principles.

In *The Sinews of War: Army Logistics 1775-1953*, Huston outlines 14 principles of logistics: "First with the Most, Equivalence, Materiel Precedence, Economy, Dispersion, Flexibility, Feasibility, Civilian Responsibility, Continuity, Timing, Unity of Command, Forward Impetus, Information, Relativity."[43] It is clear that Huston's principles are intended to be a list of things to do vice a description of how to approach logistics challenges, the latter being the focus of this article's principles. Similarly, Thompson makes use of the *British Principles of Administration* as a reference for general logistics principles in his book *The Lifeblood of War: Logistics in Armed Conflict*. Thompson's principles—foresight, economy, flexibility, simplicity, cooperation—are fewer and broader in scope than Huston's but still, to a large extent, focus on what to do rather than how to think.[44] If viewed on a continuum with the right being the pragmatic *how to* and the left being the thought-provoking paradigm, Huston's principles would be on the far right, Thompson's somewhere between the middle and the right, and this article's principles would be past the middle and more toward the far left. There is no particular spot on the continuum that is particularly better than the other. However, as one moves from the right to the left, the focus becomes more broad, but the principles' applicability also increases to a larger number of situations. Admittedly, moving to the extreme left of the continuum is of little use because the principles would be so broad that, although they would surely apply to any situation, they would be of little use. The resultant guidance would be broad, with useless principles like *employ sound logistics principles* at all times and *ensure your logistics requirements are met*. Generally, an extreme point on a continuum is of little use. The principles put forth in this article, though less pragmatic than the traditional listing of *dos* and *don'ts*, are still specific enough to provide guidance while enhancing applicability by focusing on outlining a way to think instead of listing specific actions to complete.

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Much in the same manner that the logistics command and control structure should be tailored to the specific theater of operations, so should the application of technology.

Application of the Logistics Paradigm

Operational level commanders should, at the onset, endeavor to understand as much about their theater of operations as possible. Studying history, combined with genuine intellectual curiosity, will go a long way in gaining an understanding of a diverse and often multicultural theater of operations. As the perception of the operational environment becomes more clear, commanders, with the aid of their functional experts, can begin to modify their existing command structure, protocols, and organization to facilitate the proper balance between centralized control and decentralized execution. Certain tangible and intangible environmental factors will lend themselves to either a more centralized control structure or a more decentralized one. For example, a geographically vast theater of operations with diverse climates and terrain lends itself to a decentralized control structure. Therefore, the logistics policies and practices within that theater of operations should support a high level of autonomy between distinct, geographically separate units.

Much in the same manner that the logistics command and control structure should be tailored to the specific theater of operations, so should the application of technology. Advanced technology should not be forced into use in an environment in which it is not well suited. Advanced technology should not be the *square peg* forced into an inappropriate situation's *round hole.* Commanders should use the most advanced technology available that is suited for the theater of operations. For example, no matter how advanced the available motorized transportation is, if the only means of transport through a mountainous area of operations is by donkey, then donkeys should be used. It would be of greater benefit to ensure the best donkeys and donkey drivers are used than to force the use of motorized vehicles in an unsuitable environment.

The fine tuning of control practices and technology to best mesh with the environment within the theater of operations is an iterative process. As more information is obtained about both the tangible and intangible factors of the environment, adaptations to existing policies and practices will need to be made. As stated earlier, a major role of logistics is the neutralization of adverse environmental factors and the exploitation of favorable ones. As a better understanding of the environment is gained, policies and practices must be modified to best take advantage of new opportunities or defend against previously unknown adverse conditions. The discovery of a previously unknown water source could result in a change of logistics policy by allowing the practice of drinking locally acquired, fresh water. Similarly, the discovery that a local water source is no longer potable may result in changing logistics policy and banning of the use of any water found in the local area.

An excellent measure of the soundness of existing logistics policies or practices is the speed with which they can be adapted to meet changes in the environment. The speed of change is a direct function of the flexibility of the existing logistics system. It is, therefore, of paramount concern that flexibility be a core characteristic

of any logistics plan, policy, or practice. Reliance upon single sources of supply, the belief there is only one way to do something, and resistance to new ideas are key indicators of a lack of flexibility. Without flexibility, the ability to adapt slows, which, in turn, can result in an excellent logistics plan evolving into a dated, useless way of doing things. The highest degree of flexibility should be maintained in all aspects of an operation. By maintaining the highest level of flexibility, the unit's logistics policies and practices will be able to rapidly adapt to a constantly changing environment.

The previous description of how the logistics paradigm should be applied illustrates the pronounced difference between its application and the use of more traditional, list-type logistics principles. Fundamental to the logistics paradigm is its iterative and adaptive nature. It is meant to guide thought instead of specifying specific actions to take. The shortfall of any list of *to dos* is that there will always be some instance where they do not fit, are inadequate, or are the wrong thing to do. The logistics paradigm focuses on integrating logistics policies and practices with the environment in order to ensure adequate support, exploitation of opportunities, protection against threats, and the ability to adapt to change, all key abilities demonstrated during Alexander's and Sherman's campaigns and woefully lacking in Napoleon's.

An excellent measure of the soundness of existing logistics policies or practices is the speed with which they can be adapted to meet changes in the environment.

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Maintenance Organization: A Historical Perspective

Over the years, many factors have affected the way aircraft maintenance has been organized, including training requirements, technician skill levels, availability of personnel (manning levels), availability of spares, budgetary constraints, and technical systems reliability and maintainability. Historically, training requirements have increased as aircraft complexity has increased. As the manpower levels were decreased, generalist training was resumed—but only until aircraft complexity drove the need for greater specialization.

Maintenance Organization During the Early 1900s

World War I, Decentralized Maintenance

Prior to 1917, the flying squadron had evolved as the established tactical unit. The squadron commander was responsible for upkeep and repair of all airplanes and equipment under his command. Aviation mechanics, enlisted men of any grade, were appointed after testing. There was a basic company and section formation; officers were pilots who were also in charge of section maintenance. Aircraft were technologically unsophisticated, and enlisted personnel were experts on the entire aircraft.

After World War I, when Major General Mason M. Patrick became chief of the Air Service, he issued Memorandum No 37, which established the Air Service plan for the supply, salvage, and repair of airplanes. The effect of this memorandum was to establish echelons of maintenance, which would be the accepted structure and the basis for different repair levels and locations for many years. The plan called for a network of groups, mobile parks, air depots, intermediate depots, depots, acceptance fields, and production centers. The first echelon cited in the memorandum was the group, made up of squadrons, which performed aircraft and engine maintenance repairs at the local level. The group was designed to be a self-

Maintenance Organization: A Historical Perspective

During the 1920s, as equipment advanced, maintenance at the squadron level improved with the introduction of aircraft record keeping (such as aircraft condition record, record of receipt of the airplane, and daily airplane crew report).

contained unit, not constrained with heavy equipment that would hinder its mobility.[1]

The rapid growth of aviation during World War I increased the need for airplane mechanics and engineering officers. By 1918, the aero squadron was established. The aero squadron consisted of four sections: headquarters, engineering, supply, and flying. Maintenance was within the engineering section. For airplanes, a repair crew—consisting of a crew chief, an assistant crew chief, and various mechanics—was established. The crew chief was the individual responsible for all servicing and repair of the aircraft. Soon after entry into World War I, maintenance organizations at flying fields could not handle overhauls and complicated repairs, so maintenance depots were established, centralizing some repair. The depots were located in Dallas, Texas; Montgomery, Alabama; and Indianapolis, Indiana.[2]

During the 1920s, as equipment advanced, maintenance at the squadron level improved with the introduction of aircraft record keeping (such as aircraft condition record, record of receipt of the airplane, and daily airplane crew report). The introduction of instruments, cameras, radios, and armament—still relatively simple machines—brought about the first major specializations. Training of airplane mechanics was still very broad. The mechanic was qualified in all systems except armament, camera, and radio. This generalist training led to the establishment of a crew chief system of maintenance. The crew chief became a second-term master mechanic and a graduate of Chanute Field, Illinois, master mechanics courses. The crew chief and his crew members maintained the airframe, engines, controls, and accessory systems. The specialist who was not assigned to the crew maintained armament, cameras, and radios. The specialists were assigned to a service squadron or company, usually collocated on the flying field, and performed maintenance beyond the capability of the crew chief and his crew.[3]

World War II, Centralized Maintenance

By 1939, the Army Air Service was still relatively small, with an inventory of fewer than 2,000 aircraft. The Air Service's Engineering Division at McCook Field, Ohio, was combined with the Supply Division and the Industrial War Plans Division and moved to Wright Field, Ohio. This new organization was titled the Materiel Division. It was responsible, in part, for establishing maintenance criteria, policies, and procedures and for exercising authority over all maintenance performed at flying units throughout the continental United States (CONUS).[4]

Using the cumulative experience of World War I and the postwar period, the newly named Army Air Corps gradually evolved into a new version of the echelon maintenance system. First echelon maintenance was work accomplished by the crew chief of the basic combat unit and included pre- and postflight inspections and minor repairs and servicing. Second echelon maintenance was accomplished by the crew chief with assistance from service squadron shops and included periodic inspections, adjustments or replacement of equipment, and engine changes. Third and fourth echelon maintenance was done at subdepots and depots.[5]

Maintenance Organization: A Historical Perspective

The first significant effects of technology on maintenance were seen with the adoption of metal tubing and pressed metal construction. These materials required a new class of skilled mechanics to handle the welding and riveting operations. The all-metal aircraft had controls, armament, and even landing gears that were tucked away out of the slip stream to increase speed, range, and performance. Accessibility decreased, making maintenance on these systems more difficult. One other significant change concerned the method of determining aircraft overhaul. The old method of the engineering officer's determining when the aircraft required depot overhaul finally evolved to the 1939 policy of using flying hours as the criterion.

World War II led to enormous growth in the Army Air Corps. In maintenance, flight chiefs and line chiefs became maintenance officers overnight; apprentice mechanics became line chiefs. The demand for mechanics exceeded the supply. The course length at Chanute was reduced to get mechanics into the field sooner. The broadened crew chief training was replaced by shorter, specialized training, producing the modified crew chief system. The new system included a crew chief with a crew of airplane general and engine mechanics who were responsible for flight line and periodic maintenance. A pool of specialists was located within the squadron to aid the ground crew. The large number of people involved in aircraft maintenance drove the need for a structured maintenance organization in the combat group to replace the previous year's approach of operating under each flying squadron.

World War II led to enormous growth in the Army Air Corps. In maintenance, flight chiefs and line chiefs became maintenance officers overnight; apprentice mechanics became line chiefs. The demand for mechanics exceeded the supply.

During this era, overseas theater commanders were allowed to modify or even ignore the maintenance organization structure that was mandatory in CONUS.[6] These overseas units were varied and adapted to local situations. The maintenance situation overseas was one of hard, long hours, but the outlook was generally bright, with rapid promotions, excellent parts availability, development of excellent skills, and units of high-capacity and high-quality maintenance.

Overseas operations contrasted starkly with stateside conditions, where aircraft were limited and often war-weary assets brought back from overseas, supplies were limited, and maintenance personnel were often inexperienced trainees. The stateside requirement was still one of vast amounts of flying time to train combat crews and constant recycling of trainees. These conditions prompted a high degree of specialization; teams and functional groupings of maintenance personnel were established in a dock system where hangar crews accomplished scheduled inspections in accordance with jobs that were sequenced. For each task, people were trained solely against that task. Workflow through the dock was carefully scheduled, and postdock maintenance was developed to clean up carryover work. Engine buildup went through the same high degree of specialization. The result, organizationally, was a mandated, highly structured organization to manage these specialized assets.

A combat group had a commander for all group maintenance, which was done in a maintenance section headed by an engineering officer. The section was divided into two branches: a flying line maintenance branch and a production line maintenance branch, each headed by an assistant engineering officer. The flying

Maintenance Organization: A Historical Perspective

Prior to the National Defense Act of 1947, which established a separate Air Force, maintenance organizations had many top-level maintainers but few skilled mechanics. A huge postwar loss of skilled mechanics, no strong enforcement of any maintenance system, and the introduction of new jet-powered aircraft in the form of the Lockheed P-80 led to these conditions.

line maintenance branch was broken into four units: one each for maintenance, servicing, armament, and communications. This branch was responsible for servicing, preflight, daily and 25-hour inspections, filling out forms, all contact with aircrews, replacement of aircraft and engine units (unless it would involve excessive out-of-commission time), and accomplishment of technical order changes.

The production line maintenance branch consisted of 14 units: one each for cockpit and cabin, cleaning, flight controls and surfaces, hydraulic and landing gear, engine, fuel and oil, electrical, instrument, propeller, armament, communications, metal repair, ground equipment repair, and parachute. This branch was responsible for washing and cleaning; accomplishment of 50-hour, 100-hour, and other periodic inspections; engine changes; and technical order changes beyond the capability of the flying line maintenance branch. The production branch also changed major assemblies; did metal repair and maintenance and servicing of flight line and hangar equipment; and prepared engines and aircraft for return to supply or depot and aircraft for return to depot.[7]

Post-World War II, Decentralized Maintenance with Centralized Control

After World War II, regulations began to be used to define maintenance organizations. These regulations reflected both previous experience and the changes brought about by differences in technology, personnel availability, and mission requirements. In August 1945, the US Army Strategic Air Forces published Regulation 65-1, *Combat Maintenance Procedures*.[8] This publication established a decentralized maintenance section with strong centralized control in the form of wing maintenance control. It also provided for a combat maintenance officer and specialized maintenance organizations, including flight line maintenance, scheduled maintenance, engine buildup, and servicing. This regulation set the stage for postwar maintenance organizations and procedures.

Prior to the National Defense Act of 1947, which established a separate Air Force, maintenance organizations had many top-level maintainers but few skilled mechanics. A huge postwar loss of skilled mechanics, no strong enforcement of any maintenance system, and the introduction of new jet-powered aircraft in the form of the Lockheed P-80 led to these conditions. Prior to establishment of the new service, Army Air Forces Regulation 65-1, *Supply and Maintenance Program of the Army Air Forces*, was released as a revision to the former 65-1. This revision did little other than to call out the new terminology (organizational, field, and depot maintenance) replacing the older echelon maintenance concept. On the flight line, virtually nothing changed, because the functional organizational structure remained unaffected.

Establishment of the Air Force

A Standardized, Decentralized Maintenance Structure

Standardization of the wing and base organization under what was called the Hobson Plan was the Air Force's first action affecting maintenance.[9] The Hobson Plan replaced

the World War II combined Combat and Service Group to provide unity of command and make the best use of what was a diminishing postwar personnel pool.[10] Four groups were established: the combat group, maintenance and supply group (M&S), airbase group, and medical group.[11] While organizational maintenance was placed in the combat group under the flying squadron commander, field maintenance was placed under the maintenance and supply group.

Because of greatly reduced flying requirements, top-heavy manning from experienced noncommissioned officers, and the relative simplicity of aircraft after World War II, the more traditional crew chief system was largely restored. These crew chiefs managed all work on an aircraft and supervised a team of mechanics in a classic, decentralized maintenance posture. The crew chief only occasionally had to request assistance from the field maintenance (third echelon) organization.

Berlin Airlift, Centralized Maintenance

Between June 1948 and September 1949, what became known as the Berlin Airlift was conducted. Maintenance for this airlift effort was organized as described in the Hobson Plan. Lieutenant General Curtis E. LeMay, commander of United States Air Forces in Europe (USAFE) at the time, determined that the crew chief system could not be adapted to work in the around-the-clock flying situation because of the limited number of hours a person was permitted to work. He decided that the only system capable of filling the requirements was the specialized, centralized maintenance system.

Thus, specialized aircraft maintenance was again employed, this time to support the Berlin Airlift.[12] Depot support was used extensively, and a central engine buildup line was operated at Rhein Main AB. Two 100-hour inspections were accomplished at Burtonwood Air Depot, and contractors in CONUS did 1,000-hour overhauls of C-54 aircraft.[13] The Berlin Airlift saw the first formation of a central production control at the Combined Airlift Task Force (CATF) Headquarters at Rhein Main. The central production control for airlift forces was established to monitor maintenance status, location, supply status, and other related maintenance data for all CATF aircraft. The consolidated control center scheduled all work for Burtonwood and CONUS with all lift bases.[14] An electronics squadron was formed, located in Berlin, to repair C-54 radio and radar components. The Berlin Airlift adapted the existing maintenance system, centralizing control, specialist maintenance centers, and extensive depot assistance. Another important adaptation was in the role of top-level command (leadership) in advocating or mandating major command (MAJCOM) or Air Force maintenance policy.

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The 1950s, A Variety of Maintenance Organizations

LeMay became commander of the Strategic Air Command (SAC) in late 1949. Shortly after, SAC adopted a more specialized maintenance concept. SAC Regulation (SACR) 66-12, *Maintenance Management*, was written to "establish a functional aircraft maintenance organization within the wing/base organization, which would ensure full utilization of personnel and facilities to produce maximum availability of aircraft."[15] This required organizational change

Maintenance Organization: A Historical Perspective

Air Defense Command (ADC) was having considerable trouble maintaining the new F-86D aircraft with its airborne radar and integrated electronic fuel system control. To counter the problem, ADC relied on specialists' being given more extensive training and improved specialized technical orders and instructions. The result was reduced accident rates and higher aircraft availability for the F-86D.

marked the first formal move toward centralized maintenance in the Air Force. The M&S group was disbanded, and three maintenance production squadrons were established: field maintenance, periodic maintenance, and electronic maintenance. The organizational maintenance capability was retained in the operational flying squadron in the combat group.[16] The main agency in this new structure was the wing maintenance control, which was responsible for the centralized direction and control of the wing's maintenance effort.

Other MAJCOMs were experimenting with different maintenance organizations during this period. Most retained the M&S group and were based on the crew chief's being supported by specialists where organizational maintenance was under the operational squadron commander.[17] The exception was Air Training Command (ATC), where the organizational maintenance squadron (OMS) was under the M&S group commander because of ATC's limited mobility requirements. In SAC and Tactical Air Command (TAC), when units deployed, they included specialists from the M&S group in order to be a self-sufficient deployed organization. The Military Air Transport Service (MATS) used a variation of specialized maintenance. All commands faced skilled personnel shortages.

In June 1950, the North Koreans invaded South Korea, and the United States again was involved in an armed conflict. The standard M&S system in place at the time—even SAC's version under SACR 66-12—was not suitable for meeting mission requirements, largely because of combat conditions and inadequate forward-based facilities from which to conduct maintenance operations. Consequently, a system of rear-echelon maintenance bases in Japan and Korea evolved. Combined with the rear units, these rear-echelon maintenance bases were known as rear echelon maintenance combined operations (REMCO).[18]

Crew chiefs at forward bases, with their crews, performed preflights, turnarounds, battle damage repair, preparation for a one-time flight to rear bases, and armament maintenance. Maintenance at these forward locations was limited to the quick-turnaround type of work aimed at keeping a maximum number of aircraft airworthy. The inability to achieve base self-sufficiency at forward locations made the REMCO adaptation necessary.

In 1953, ATC moved closer to centralized maintenance by forming periodic squadrons and placing all specialists in the field maintenance and armament sections. Also, planning and scheduling were moved to the chief of maintenance level, quality control was expanded, and dispatch of all specialists was accomplished by maintenance control.

About this time, Air Defense Command (ADC) was having considerable trouble maintaining the new F-86D aircraft with its airborne radar and integrated electronic fuel system control. To counter the problem, ADC relied on specialists' being given more extensive training and improved specialized technical orders and instructions. The result was reduced accident rates and higher aircraft availability for the F-86D.[19] This concept of breaking out aircraft systems into functional areas, with each area maintained by its own specialist, eventually was approved by the Air Staff and continually expanded as newer aircraft and significantly more complex systems were introduced into the inventory.

Also in 1953, the Air Force Inspector General (IG) began to question whether the montage of different maintenance concepts among MAJCOMs was serving the best interest of the Air Force. In a landmark semiannual report to the Chief of Staff, he pointed out:

> As a result of over one hundred (100) inspections, both readiness and technical, conducted by this office, it was determined that no universally effective specialized and standardized system of aircraft maintenance existed in the Air Force. The one notable exception is the Strategic Air Command, which has made a concerted effort to achieve a modern concept of maintenance and was experiencing excellent results in the conservation of skills, tools, facilities, and materials. Other commands, however, were employing various methods and systems of aircraft maintenance largely at the discretion of local commanders and maintenance officers.[20]

In December 1953, the Air Force published Air Force Regulation (AFR) 66-1, *Maintenance Engineering*. It was the first Air Force regulation dealing with maintenance management. Only four pages in length, it defined three levels of maintenance (organizational, field, and depot). It temporarily gave MAJCOMs authority to tailor maintenance organizations to suit their missions and types of aircraft. But it issued this caveat:

> Frequent reexamination of the Air Force maintenance structure will be made to ensure that organizations, facilities, equipment, and specialists are available and fully able to meet the support requirements of newly introduced items of equipment or weapon systems.[21]

In early 1955, the Air Staff initiated a study at Dover AFB, Delaware, a large MATS flying wing. Conducted by an Air Force management engineering team, the study proposed that organizational maintenance be removed from the operational flying squadron and consolidated with field maintenance under a wing chief of maintenance.[22] After 9 years as a service, the Air Force published definitive guidance on maintenance organizational structure on 1 September 1956. That guidance, in Air Force Manual (AFM) 66-1, *Maintenance Management*, was patterned after SACR 66-12 and incorporated the basic guidelines of AFR 66-1 and its revisions.

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AFM 66-1, Centralized Maintenance

AFM 66-1 established a chief of maintenance responsible for all aircraft maintenance in the wing and reporting directly to the wing commander. The chief of maintenance was assisted by a staff to help in central control of all maintenance activity. Three squadrons worked directly for and reported to the chief of maintenance: the organization maintenance squadron, field maintenance squadron, and electronics maintenance squadron. The actual organizational structure was not new; it was a formalized version of existing structures. The manual set Air Force standards, goals, and objectives for maintenance, which included aircraft in-commission rates, component repair standards, and aircraft scheduling objectives, among many others. It also established the requirement for man-hour accounting and maintenance data collection, a major initiative.

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When AFM 66-1 was first published, implementation was a MAJCOM option. It met with numerous objections and, other than in SAC, only perfunctory compliance. Operational flying squadron commanders were leery of the "new and yet unproven system."[23] The centralized control aspect of AFM 66-1 meant to many that organizational maintenance would be taken out from under operations control. Centralized control of maintenance had the support of Air Force Chief of Staff General Thomas D. White, however, and in 1958, he made it mandatory for all Air Force organizations.[24]

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As directed, all commands began to use AFM 66-1 in the 1960s. The increasing complexity of aircraft and the need for greater specialization saw more acceptance of centralized maintenance. Crew chiefs assigned to OMS worked on the flight line, assisted by other OMS (airplane general) resources. All other specialist personnel were assigned to either a field maintenance squadron or electronic maintenance squadron and later to armament and electronics squadrons and to munitions maintenance squadrons. These specialist personnel were located off the flight line and were dispatched to assist crew chiefs as necessary, requiring communications and coordination through job control (chief of maintenance staff personnel), which, in turn, required paperwork and documentation. This process involved high numbers of overhead persons, who were not directly involved in sortie generation on the flight line.[25]

Complex systems introduced with century series aircraft (particularly F-101, F-102, and F-106 aircraft) assigned to the Air Defense Command and similarly complex systems on SAC bombers drove the development of large numbers of specialists, particularly in avionics squadrons and, to a lesser extent, munitions maintenance squadrons. Systems aboard these modern fighter and bomber aircraft were so numerous and complex that technical schools generally required 52 weeks to complete technician training. Even then, further on-the-job and field training detachment training was required once the technician arrived at an assigned unit. Systems often failed, and repairs were lengthy. Only through specialist pools (mixtures of personnel with back-shop experience and personnel with on-equipment experience) could demands be met.

When new weapon systems were brought into the inventory, large cadres of technical representatives, many of them engineers, were provided by the prime and original equipment manufacturers. These technical representatives were used both for training and hands-on maintenance and had priority access to their firms' technical staffs.

Indeed, these factors, combined with others, produced high Air Force tactical fighter mission capable (MC) rates through the 1960s. The Air Force F-4 Phantom series aircraft was relatively new. Contractor technical representatives were embedded in maintenance organizations, and a large number of them were assigned across CONUS and Southeast Asia (SEA) units. Funding was readily available for SEA operations. The quality of both officer and enlisted training improved, and course durations increased. The senior workforce and management experience increased.

Vietnam Conflict, Decentralizing Trend

AFM 66-1 was practical for all MAJCOMs and gained general acceptance, but it was seriously tested, particularly in TAC, during the Vietnam era. Depending on existing manning levels, deployments may have made it difficult to cover specialist support requirements. Early deployments of smaller units (squadrons) to participate in the Vietnam conflict had austere manning, creating maintenance deficiencies and long hours of work. But temporary duty gave way to permanent change of station assignments, and squadrons often deployed with the same personnel assigned to them at home stations. The Air Force placed flight line maintenance back into the tactical squadrons under operations. Personnel were identified with squadrons in CONUS so that peacetime work integrity would be maintained when deployed.

In the Pacific Air Forces (PACAF), PACAF Regulation 66-12 was issued. This regulation realigned the OMS maintenance officer administratively to the flying squadron but left him working for the chief of maintenance. The flying squadron commander thus rated OMS personnel even though they functionally worked for the chief of maintenance.

In 1966, TAC published TAC Manual (TACM) 66-31, instituting what was known as *TAC Enhancement*. Flight line personnel moved from OMS into the tactical flying squadrons. Munitions load crews were likewise moved, phase was moved into the flying squadron from field maintenance squadron, and some specialist support was placed into the flying squadron for limited on-aircraft work, primarily removal and replacement of components.[26]

The new program was described in *TAC Attack* as an:

> …interim reorganization (which) will enhance the efficiency of maintenance functions within deployed and dispersed unit … from the moment they deploy. Continuity of supervision will not be interrupted. Squadrons will be better able to cope with the unavoidable problems of dislocations. Overall, decentralization will improve the capability of TAC's fight and reconnaissance squadrons to continue their worldwide mission.[27]

A little more than 1 year after LeMay retired as Chief of Staff, the tactical fighter community returned to decentralized maintenance.

The Early 1970s, Downsizing and Centralizing

Budgetary cuts accompanied the phasing down of military involvement in Southeast Asia. The duplication of resources resulting from TACM 66-31 no longer could be supported. By 1972, the number of Air Force members had dropped to its lowest since 1950, a 16-percent reduction just since 1966.[28]

Declines in MC rates for tactical fighters were related more to manpower reductions, skill-level reductions, introduction of complex new weapon systems (as with the F-111 series), increased problems with maintaining F-4 aircraft (now getting older), and spares reductions rather than to organizational structure. The move back to centralized maintenance became necessary to deal with the declining specialist availability and skill levels. The declining MC rates for these aircraft continued to grow despite the change back to the centralization that had earlier produced higher capability rates.

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Studies done in USAFE showed that the F-4 aircraft could not be turned fully mission capable on a daily basis.[29] This was primarily because of the declining mean time between failure of F-4 systems and subsystems. Similar problems with the F-111 are also well documented. There were enough F-4s to meet peacetime flying training requirements but not enough to generate the sortie surge requirements predicted under the *War Mobilization Plan*. It could be argued that no form of organization would have made a difference in maintaining these complex and low-reliability weapon systems.

On 1 August 1972, the Air Force published a major revision to AFM 66-1 that greatly expanded maintenance guidance. The new manual consisted of ten volumes that covered every detail of Air Force maintenance, including that for aircraft, missiles, and communications equipment.

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In the foreword of the new AFM 66-1, Chief of Staff General John D. Ryan said:

> Economy in the use of resources can only be achieved by balancing operational requirements and maintenance capability. This requires planning and comprehensive scheduling of equipment maintenance. Management effectiveness can then be measured in terms of maintenance accomplishments.[30]

The new manual emphasized "making equipment available for maintenance when the resources are available." Lieutenant Colonel Thomas E. Reiter noted in his Air War College thesis, "This was a significant philosophical change because, in the past, maintenance was performed whenever the aircraft were not on the flying schedule and the new policy basically called for the aircraft to be on the flying schedule whenever they were not required to be in maintenance."[31] This marked the first time such definitive guidance had been given from such a high level. Ryan's comments on balancing requirements in operations and maintenance and his measures of merit do not imply an organizational structure.

The strict adherence to a rigid program of reporting and documenting maintenance actions, the establishment of MAJCOM evaluation teams to ensure compliance, and rigorous IG inspections and operational readiness inspections seemed to provide a clear message that the years of flexibility in the area of maintenance organizational structure were over. This standard manual and its organization were the final authority and discouraged further innovation.

In USAFE, from 1971 to 1974, General David C. Jones, Commander in Chief, USAFE, set several initiatives in motion that would have a broad impact on maintenance organization in the future. Jones became concerned with more effective use of USAFE resources.[32] USAFE's Project Streamline evaluated extensive initiatives, including cross-utilization training of maintenance personnel. A separate initiative, briefed to Jones prior to his reassignment as Air Force Chief of Staff, dealt with centralizing maintenance even further and called for centralized intermediate repair facilities (CIRF) to support forward base operations in wartime to reduce airlift requirements and the logistics footprint.

USAFE Vice Commander Lieutenant General Louis Wilson was reassigned to PACAF to take over as PACAF Commander in Chief. He asked for a staff paper that he would use to implement the CIRF concept at Kadena AB. Jones, then Chief of

Staff, established the Maintenance Posture Improvement Program (MPIP) in 1976 to "find new ways of going about the complicated business of maintenance, which would permit more efficient and effective use of the total Air Force maintenance resources."[33] The CIRF project studies were included as part of the MPIP. The proposal in USAFE and the CIRF activities within PACAF to centralize intermediate maintenance became widely known. While there was basic Chief of Staff agreement to continue to pursue the feasibility of the proposed centralization where applicable, the proposal met with significant opposition among proponents of base self-sufficiency, particularly within TAC.

To respond to MPIP and, likewise, respond to USAFE and PACAF centralized maintenance initiatives, TAC proposed and tested a new base-level maintenance organization called the Production Oriented Maintenance Organization (POMO).

The Mid-1970s, POMO and Decentralized Execution with Central Control

POMO was designed from lessons learned from the Israeli Air Force during the 1973 Arab-Israeli war (Yom Kippur). The Israeli Air Force was able to generate high sortie rates by cross-utilizing skills of personnel and assigning them to a flight line organization where they were directly responsible for repairing, servicing, and launching aircraft. People not directly contributing to generating aircraft were assigned to back shops. A TAC team sent to Israel said the Israeli system of maintenance "appeared to have great possibilities in the fighter environment," where "rapid aircraft turnaround, sortie generation, and surge capability were essential."[34] Under POMO, specialists from the electronic maintenance squadron, field maintenance squadron, and munitions maintenance squadron were assigned directly to the flight line and placed in the same squadron as aircraft generalist crew chiefs or airframe and powerplant generalists.

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The resulting squadron was named the aircraft generation squadron instead of OMS because it was now able to handle all on-equipment maintenance. The aircraft generation squadron consisted of aircraft maintenance units, which were aligned respectively with flying squadrons. In some cases, weapons load crews also were assigned to an aircraft generation squadron as weapons maintenance units. The remaining specialists were grouped in two new squadrons—the equipment maintenance squadron and the component repair squadron—and performed all off-equipment maintenance. The POMO often is described as decentralized execution with centralized control because the chief of maintenance and his staff remained the same and maintenance and job control continued to control the entire maintenance effort.

During this same time, the F-111 ushered in a new flight line remove-and-replace (2R) era of maintenance, which meant fewer specialists were required for on-equipment maintenance. This move to 2R maintenance also resulted in less detailed technical training for many specialists. Now aircraft began to incorporate self-test/built-in-test features that eliminated the more detailed on-equipment troubleshooting seen in the past. With the introduction of avionics intermediate

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shops and modular engine components, on-equipment maintenance became less specialized.

Upon implementation, the POMO structure did not increase sortie production as expected. One comprehensive study found that POMO "has had little, if any, positive effect on aircraft maintenance in a peacetime operating environment."[35] The study found strong indications that POMO had caused some degradation in aircraft maintenance performance. It stated in its discussion of implications for management that "if the Air Force wants increased productivity, then one or all of the components of maintenance efficiency must be improved" and that "organizational efficiency has in many cases only a limited impact on the overall efficiency of a maintenance action when compared to what is embodied in the sequence of tasks required in the maintenance action itself."[36]

When General Wilbur L. Creech took command of TAC in 1978, he ordered his own study. It found that sortie production had fallen 7.8 percent from 1969 to 1978 and concluded that this decline was attributable not to external factors but simply to maintenance's inability to produce the required sorties.

The Late 1970s and 1980s, Increased Decentralized Execution, Less Centralized Control

When General Wilbur L. Creech took command of TAC in 1978, he ordered his own study. It found that sortie production had fallen 7.8 percent from 1969 to 1978 and concluded that this decline was attributable not to external factors but simply to maintenance's inability to produce the required sorties.[37] The new TAC Commander felt the organization of maintenance was a major factor in this decline and led TAC to create the Combat Oriented Maintenance Organization (COMO), formalized under TAC Regulation (TACR) 66-5.

TACR 66-5 differed from POMO in many ways. Each squadron aircraft maintenance unit now performed its own scheduling and was responsible for its own utilization rate. Each squadron aircraft maintenance unit had its own dedicated analyst. Supply was decentralized to each aircraft maintenance unit, and the wing-level maintenance supply liaison was eliminated. Each squadron aircraft maintenance unit performed its own debriefing, had its own pool of aerospace ground equipment, and dispatched its own flight line personnel to jobs. And a dedicated crew chief was assigned to each aircraft. The deputy commander for maintenance (DCM) remained responsible for all maintenance and reported to the wing commander. Maintenance control now *coordinated* maintenance activities more than it *controlled* maintenance. COMO also proved to be very manpower intensive.

The MC rates for tactical fighters continued to increase. One report declared:

> The results of the transition to COMO have been dramatic. Sortie production, from the third quarter of 1978 to 1983, rose at an annual rate of 11.2 percent. In the first full year under COMO, 1979, TAC flew all its programmed sorties for the first time in a decade.[38]

In 1990, the MC rates increased to an all-time high of 88.4 percent. When considering the increased sortie rates reported by TAC between 1978 and 1983 and beyond, however, consideration needs to be given to the fact that the period also saw a changeover to more modern and more reliable tactical aircraft, better technical data through the introduction of job procedural aids and guides, better automatic test equipment, and more accessibility and better maintainability

because of technology advances and lessons learned from F-4 and F-111 problems. All could have had an impact on the increased MC rates.

Interviews with senior maintenance officers indicated that the senior management workforce during the changes to COMO had considerable experience and careful career management. The rated supplement (to maintenance) and the maintenance officer career fields both had specialized career management through the Military Personnel Center. The rated supplement had its own branch, and Palace Log was established within the Officer Management Division, both carefully managing individual careers and tracking high performers and assisting them to grow into commander's jobs and DCMs. Palace Log often took in first assignment instructor pilots who had finished their tour teaching new pilots and could find no open cockpit slots. They were then placed in maintenance and became advocates of maintenance as they progressed through their rated careers.

In addition, there was consensus among the senior maintenance managers interviewed that, during COMO, there was a highly trained professional maintenance workforce backed up by senior technicians who had considerable skill in the older mission design series that would soon be replaced by newer, more reliable, and easier-to-maintain tactical aircraft. These professional maintainers saw COMO as more effective than–but perhaps not as efficient as–the previous, centralized maintenance. It is also important to understand that the transition from POMO to COMO was not a major reorganization but, instead, a realignment of responsibilities and functions.

The Early 1990s, MAJCOM-Specific Maintenance Organizations

MAJCOMs in 1990 were operating mostly in modes acceptable to each while still pursuing optimal maintenance concepts more suited to ever-changing operational requirements. Tactical air force MAJCOMs finally had adapted COMO to their requirements. SAC formally implemented a decentralized structure in 1987, the implementing directive being SAC Regulation 66-14, *Readiness-Oriented Logistics System (ROLS) Maintenance Management General Policy, and Deputy Commander for Maintenance (DCM) Staff Activities*. ROLS was similar to COMO and obviously influenced by it, but AFM 66-1 was still visible.[39] The Military Airlift Command (MAC), the most consistent of the MAJCOMs in terms of maintenance organizational structure, remained committed to centralized maintenance; its implementing directive was MAC Regulation 66-1, *Maintenance Management Policy*.[40]

MAJCOMs in 1990 were operating mostly in modes acceptable to each while still pursuing optimal maintenance concepts more suited to ever-changing operational requirements.

During Desert Shield and Desert Storm:

> …maintenance organizations were to be aligned under AFM 66-1 procedures.… The CENTAF/LGM was a staff advisor to deployed wings. Each base installation having more than one wing would have a lead unit DCM who would then appoint senior tenant wing maintenance officers as assistant DCMs. Collocated units were to be prepared to form joint maintenance operations centers (JMOCs) and job control (JC) units.[41]

In fact, each MAJCOM maintained aircraft in accordance with its peacetime organizations.

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When General Merrill McPeak ordered the change to the objective wing, he was issuing a major change to the combat air force, although the objective wing was an effort to standardize organizations across all commands in the Air Force. This standardization effort, which applied to all Air Force wings, was based on McPeak's description as "one base, one wing, one commander."

The one notable difference from tactical fighter support in peacetime was the establishment of CIRFs out of theater (in USAFE or at home bases) for avionics (except electronic countermeasure pods) and engine maintenance.[42] In part, the acceptance of centralized intermediate maintenance was driven by a compromise between the need to limit population in the area of responsibility and the desire for self-sufficiency. There was concern that lines of communication would be interrupted if intermediate maintenance were out of the area of responsibility, but this concern gave way, in part, to the limited number of people the theater could support.[42]

One other major maintenance variation occurred with the establishment of the 7440th Composite Wing (Proven Force) consisting of ten different mission design series aircraft. The wing established seven aircraft maintenance units (one for each flying squadron), a combined component maintenance and equipment maintenance section, and an ammunition branch out of the 39th Consolidated Aircraft Maintenance Squadron and deployed USAFE units. The official history of Proven Force states that monitoring of the parts flow was highly effective but also was cumbersome and manpower intensive, requiring manual tracing of as many as 500 pieces of cargo each day. Proven Force MC rates were approximately the same as those for peacetime and similar models of aircraft.[45]

The Mid- and Late-1990s, Objective Wing Decentralized Structure

When General Merrill McPeak ordered the change to the objective wing, he was issuing a major change to the combat air force (CAF), although the objective wing was an effort to standardize organizations across all commands in the Air Force. This standardization effort, which applied to all Air Force wings, was based on McPeak's description as "one base, one wing, one commander."[46] It was intended (again) that Air Force wings should train as they fight. It accomplished this by having a single wing commander at each base, with flight crews and flight line maintenance personnel working for the flying squadron commander, who reports to the operations group commander. The back-shop maintenance, supply, and transportation personnel would work for a logistics group commander.

Some variations were made to this basic objective wing structure in 1992 when a deputy for operations group maintenance was created to provide overall supervision for all flying squadron maintenance, the phase docks, and interface with the logistics group commander to resolve issues with back-shop or other supply and transportation support of sortie generation and phase activities. Maintenance control had become the maintenance operations center under the wing. Quality assurance was also under the wing. The net result for CAF units was to return them more closely to traditional squadron maintenance. The logistics interface with organizational-level maintenance (sortie generation) was minimal except through interface with the operations group, and in some instances, a maintainer did not fill the logistics commander billet.

Several MAJCOMs had objective wing variations approved, permitting them to keep all maintenance responsibilities under the logistics group commander. These were Air Mobility Command (AMC), ATC, Air Force Special Operations Command, the Air National Guard, and the Air Force Reserve Command.

Two other major changes took place in the 1990s that would not impact the objective wing structure directly but would introduce new considerations to the conduct of maintenance on a broader scale. The first was the formation of the Air Combat Command on 1 June 1992. The distinctions between tactical and strategic aircraft were blurred by operations in Vietnam (bombers doing tactical missions). During Desert Storm, the Secretary of the Air Force, Chief of Staff, Vice Chief, and TAC and SAC commanders all spearheaded the drive to integrate the assets of SAC and TAC into a single operational command. At the same time, MAC reorganized by consolidating airlift and most refueling assets under a single umbrella, the new AMC. AMC provided the *global reach* facet of the Air Force mission, while the new ACC provided the Air Force's *global power*.[47]

The second change was the formation of the expeditionary air force (EAF) in response to both an evolving world situation with popup contingencies in places where the Air Force had rarely operated before and continuing steady-state regional security commitments far from any Air Force main operating base. The organizational aspects of the transition to the EAF resulted in the designation of ten air and space expeditionary forces (AEF) that rotate their availability for deployment and rapid response on a periodic basis. This required the establishment of a global system of CONUS support locations, forward support locations, and forward operating locations (FOL), all of which have affected maintenance operations in that units at FOLs are supported much the same way as squadrons at forward bases were supported during the Gulf War.[48] The relatively autonomous CAF flying squadron under the objective wing was seen as conducive to EAF and AEF operations.

In February 2002, General John Jumper, Chief of Staff of the Air Force, put together a working group to examine a standardized wing organizational structure. The purpose of the working group was to present a new wing and group organizational structure designed to meet the needs of the AEF. Jumper, as well as other Air Force senior leaders, had determined that an organizational restructure was needed to improve combat readiness and enable the Air Force to focus on its core disciplines.[49]

On 25 March 2002, Jumper and the MAJCOMs approved the new combat wing organization structure. On 22 April 2002, Jumper sent out a message via the Defense Messaging System informing Air Force personnel of this new, standardized wing structure.

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The new wing structure consists of four groups: the operations group, maintenance group, mission support group, and medical group (Figure 1). Their responsibilities are as follows:

- **Operations Group.** Operations group activities will focus on planning and executing air and space power.
- **Maintenance Group.** Aging fleets and years of resource shortfalls require increased attention to the balance of sortie production and health of our fleet.
- **Mission Support Group.** The Air Force will develop a career path for commanders who understand the full scope of home-station employment and sustainment and deployment, beddown, and sustainment at contingency locations: crisis actions,

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force protection, unit type code preparation, load planning, communications, en route visibility, reception, contracting actions, bare base and tent city preparation, munitions site planning, personnel readiness, expeditionary combat support, and so on.

- **Medical Group.** Medical groups will continue to focus on maintaining a fit and ready force.[50]

Conclusions

Throughout its history, the Air Force has moved between centralized and decentralized, standardized and MAJCOM-varied maintenance organizations, often in response to changes in budgets, resources, and technology. Transformation is likely to continue, and organizations will likely continue to evolve to support changing mission requirements within current resource constraints.

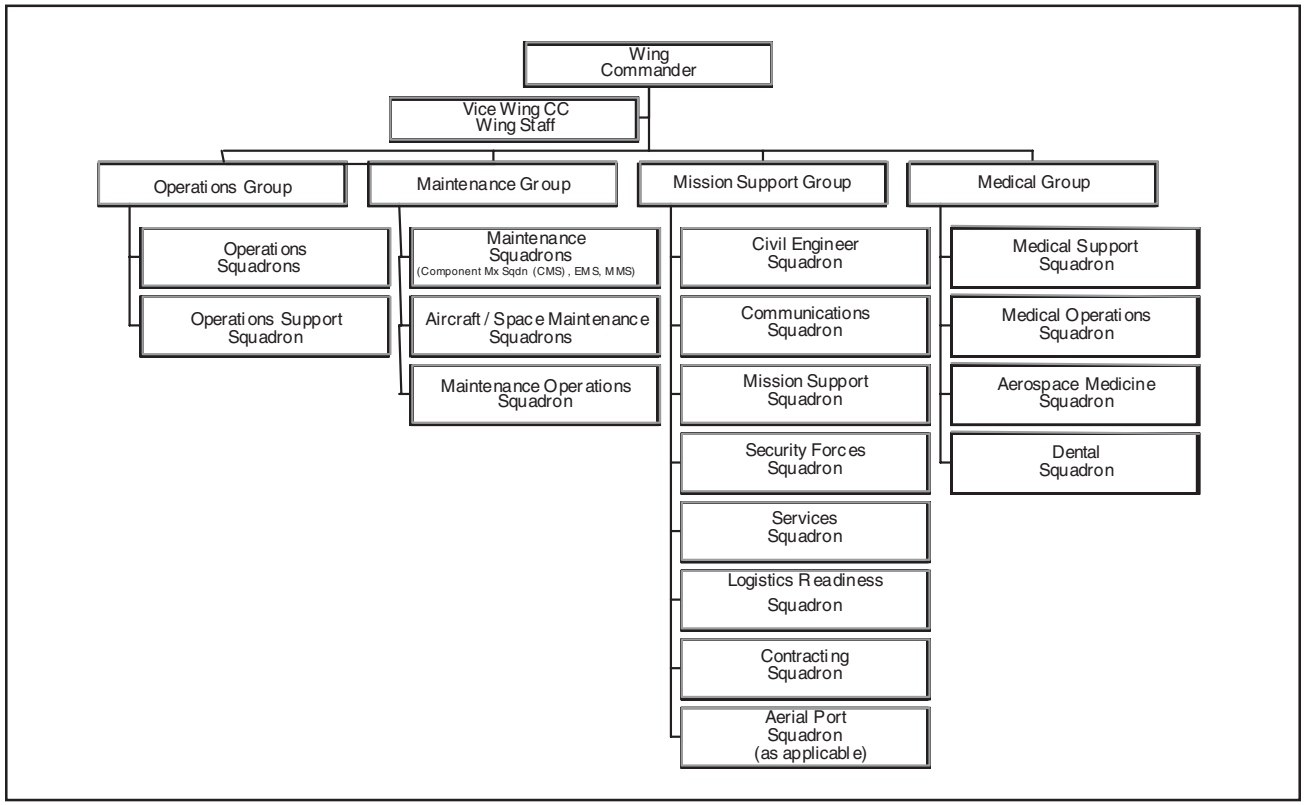

Figure 1. Combat Wing Organization[50]

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Transporting Munitions

Throughout history, great armies have successfully used a transportation infrastructure to create their greatest asset—mobility for their expeditionary forces. The forces of Alexander the Great, the Ottoman Empire, Napoleon Bonaparte, and Ulysses S. Grant successfully used their own or their host nation's transportation infrastructures to enhance mobility. Their successes occurred because they had an efficient means of transportation and transportation infrastructure with which to be supplied. In contrast, during World War II, the German Army could not be resupplied during Operation Barbarossa, thus denying the mobility on which the blitzkrieg was based. Air Force leadership for the aerospace expeditionary force (AEF) must understand how a host nation's transportation infrastructure affects munitions flow to the warfighter.

A responsive transportation system, integrating commercial and military modes, must be considered and evaluated. Operation Allied Force proved movement of US munitions is dependent on a host nation's transportation infrastructure. The lessons learned from historical applications of a transportation infrastructure necessary to support munitions movements can be applied to today's AEF.

Logistics was the basis of Alexander the Great's successful strategy. It was the most responsive and flexible force in existence because of its small logistics footprint. Philip, Alexander's chief logistician, ensured the troops carried their own arms, armor, and some provisions while marching, compensating for the lack of a transportation infrastructure. Oxen and oxcarts were not used. Oxen could achieve a speed of only 2 miles per hour, their hooves were unsuitable for carrying goods for long distances, and they could not keep up with the army's daily marches, which averaged 15 miles per day. The army did not use carts or servants to carry supplies, as was the practice of contemporary Greek and Roman armies. Horses, camels, and donkeys were used in Alexander's baggage train because of their speed and endurance. As necessary, roadbuilders preceded the army on its march to keep the planned route passable.[1]

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Alexander depended on host-nation support to keep the routes his armies traveled open and protected, very much like what is called for in the Joint Vision 2020 doctrine of multinational operations.[2] While marching through arid areas, such as present-day Greece and Turkey, Philip provisioned depots throughout regions where grain and water were not available. To enable this, Alexander secured the alliance of people along the route who would be responsible for supplying the depots and protecting the routes his army would use.[3] Transportation routes used to bring supplies were guarded heavily; their primary purpose was to ease the passing of marching troops and animals to the storage depots.

Many of these same ancient roads are still in use today, some even with the original engineering infrastructure. One such bridge, the Saint Julien, was constructed by the Romans in the 3d century BC in the Provence region of present-day southern France and spans the Coulon River. To this day, the bridge supports normal vehicle traffic. As archers' missiles evolved to the use of cannons in the 14th century, even well-built roads and bridges, such as the Saint Julien, could not quickly accommodate heavy-footprint items like cannons.[4] However, the Ottoman Empire overcame this handicap in the 15th century.

The Ottoman Empire

The Ottoman Empire, which reached its zenith in the 16th century under Sulaiman the Magnificent, stretched from North Africa to Hungary and from the Aral Sea in the east to the Caspian Sea in the west. Similar to Alexander's strategy, the key to conquering an area that size was the mobility of its army. A French traveler in the 14th century characterized the mobility of Ottoman troops with, "They can start suddenly…. When the drum sounded, they put themselves immediately to march, never breaking step, never stopping till the word was given. Lightly armed, in one night, they travel as far as their Christian adversaries in 3 days."[5] Even with the use of heavy cannons, the army could move quickly, unencumbered by the heavy logistics footprint of munitions because it created a special cannon corps to manage its munitions program.

Cannons of the mid-15th century created a challenge to mobility, and as a result, their use was initially resisted by the Ottoman cavalry.[6] These bronze cannons typically were 12 to 15 feet long with diameters of 30 inches or greater.[7] Under the reign of Murat II (1402-1451), the Ottomans created a cannon corps, known as the *Topçu Ocaðý,* to manufacture and use cannons. Murat II's son, Mehmed II, established a cannon wagon corps, known as *Top Arabacý,* to transport arms and munitions during campaigns. Additionally, a specialized fleet of boats carried cannons. Foundries were built in different parts of the empire.[8] The Ottoman cannons, powerful enough to knock down the walls of Constantinople during a 53-day siege in 1453, were cast outside the city walls.[9] The furnaces and molds to make the cannons were placed outside the walls, and the raw materials were brought there.[10]

In terms of transporting firepower, the Ottomans moved 80 ships overland from the Bosphorus Sea to the Golden Horn to get a better strategic fighting position for the siege of Constantinople—the transition of the fleet allowed them to subject Constantinople to siege from any side. The Golden Horn was the waterway that served as the city's harbor and was protected with metal chains, preventing the entrance of the Ottoman fleet. Mehmed II's engineers built a road that rose 200 feet above sea level, upon which was laid a track of greased timbers. The ships were pulled out of the water and laid on metal-wheeled cradles. Teams of men and oxen pulled the entire 80-ship flotilla 1,400 feet overland from the Bosphorus to the Golden Horn.[11] Thus, whether lightly armed or bearing heavy cannons or foundry equipment, the Ottomans delivered the firepower necessary to build an empire.

Napoleon and Transportation Infrastructure

Like the Ottomans, Napoleon Bonaparte created a munitions transportation infrastructure. The mobility of the Napoleonic armies was tied to the mobility of their supporting munitions infrastructure. In his book, *Essai Général de Tactique*, written in 1772, Comte de Guibert's vision of battlefield mobility greatly influenced Napoleon Bonaparte. De Guibert wished to end the practice of private contractors delivering supplies from rear magazines to armies on the march. He believed supply controlled a general's movements because he was ignorant of the working of the supply system. "It is a fundamental error to separate the science of subsistence from the science of war."[12] He stressed that army officers should learn supply.[13]

Like the Ottomans, Napoleon Bonaparte created a munitions transportation infrastructure.

De Guibert proposed a reduction in the weight of artillery to increase its mobility. His goal was to allow the troops to have the maximum firepower with their mobility so they could be directed at a weak point and overcome the enemy.[14] De Guibert advocated mobile field artillery because large quantities of artillery and support for them hindered an army's mobility.[15]

In 1805, when Napoleon went to war against Austria, he ushered in a new logistics concept of constant resupply by supply convoys. In a matter of weeks, he assembled a supply and transport system for a 170,000-man army. Similar to Alexander, Napoleon's staff sent dispatches to cities along the proposed routes to secure provisions and supply the army along the way. Through Heilbronn, Germany—possibly the first recorded munitions depot in Western warfare—flowed 75,000 to 100,000 rounds of ammunition during the Austrian campaign. In addition to the munitions depot at Heilbronn, Napoleon had a military transportation system, consisting of wagons and boats, to move the munitions needed to support the artillery; he allocated 2,500 of 4,500 wagons to support the artillery. In 1807, Napoleon replaced hired vehicles and drivers with fully militarized transportation personnel and equipment.[16]

Grant and the Necessity of Surface Transportation

In terms of transportation infrastructure, one has only to read the Civil War dispatches of General Ulysses S. Grant. His concern for transportation infrastructure is summed

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up in the first paragraph of his report of the US Armies 1864-1865 to E. M. Stanton, US Secretary of War. Grant relayed (despite the numerical inferiority of the Confederate Army):

> The resources of the enemy and his numerical strength were far inferior to ours; but as an offset to this, we had a vast territory, with a population hostile to the government, to garrison and long lines of river and railroad communications to protect, to enable us to supply the operating armies.[17]

Grant knew that roads, railroads, and rivers were centers of gravity around which the Civil War revolved. Railroads became the military roads for both armies, and special garrisons were established to protect them.

Grant knew resupply of the Union expeditionary campaigns depended on Confederate-controlled rails, roads, and water ports.

According to Grant, if the South could have prolonged the war, it would have won with a stalemate. "In the North, the people governed and could stop hostilities whenever they chose to stop supplies."[18] To bring the war to an end, Grant planned to have continuous operations of his forces "regardless of season or weather;" therefore, he needed to continuously supply his forces.[19]

Grant knew that roads, railroads, and rivers were centers of gravity around which the Civil War revolved. Railroads became the military roads for both armies, and special garrisons were established to protect them.[20] In February 1862, General D. C. McCallum was appointed Military Director of Railroads, with authority to take possession of railways and engines required for the transport of US troops, arms, and military supplies. The ordnance supplied for the Union came from arsenals, foundries, and armories throughout the North, incidentally located on railroads and waterways.[21]

In terms of transportation infrastructure, Major General Rufus Ingalls, Union Chief Quartermaster of the Armies operating against Richmond, stated, "In order that the enormous streams of supply may be uninterrupted, the wagon roads should be of the best construction, drained, hard and smooth."[22] Ingalls also outlined how to use the roadways to maximize logistical support.

Ingalls relayed that, at Gettysburg, all wagon trains were assembled at Westminster, approximately 25 miles to the rear. Only ammunitions wagons and ambulances were brought up to the immediate rear lines. The established priority for moving mule-driven supply trains was, "Wagons containing small-arm ammunition coming first and then those containing the ordnance, subsistence, and forage.…"[23]

Grant's goal was to have his wagons never operate more than a single day's march from their supply depots, usually at railheads or river ports. Speaking of the Army of the Potomac in 1864, he said "Too much credit cannot, therefore, be awarded to the quartermaster and commissary departments for zeal and efficiency displayed by them."[24]

In terms of the importance of munitions to the Confederacy, a law was enacted requiring any ship that entered a Confederate port to have arms or ammunition else it would be confiscated. Referring to Confederate soldiers, Captain Henry G. Sharpe wrote in 1896, "Though the soldiers were often barefoot, ragged, and hungry, they

never lacked arms, nor were they defeated for want of ammunition."[25] Nearly all Confederate States established munitions factories under the exclusive control of the Confederate Government.[26]

Grant's dispatches clearly show the importance of a transportation infrastructure to the Union and the Confederacy. In a dispatch to Major General Sheridan during the Shenandoah Valley campaign in October 1864, he said, "If you make the enemy hold a force equal to your own for the protection of those thoroughfares, it will accomplish nearly as much as their destruction."[27] The thoroughfares he refers to were the Virginia Central Railroad and canal. In the Shenandoah Valley campaign to capture the railroad, Grant said, "This road was very important to the enemy. The limits from which his supplies had been drawn were already very much contracted, and I knew he must fight desperately to protect it."[28] In another example, Grant knew the importance of the Danville railroad to General Robert E. Lee as Grant advanced on Five Forks, Virginia, prior to the battle at Gettysburg. He knew that by pressuring the Danville railroad Lee would fight. "These roads were so important to his very existence while he remained in Richmond and Petersburg, and of such vital importance to him in the case of retreat, that naturally he would make most strenuous efforts to defend them."[29]

The Road Known as the Sacred Way—Verdun, France, 1916

To bleed the French to death at Verdun, the Germans concentrated on logistical support for artillery.

Roads are not normally associated with the static trench warfare of World War I; however, the road from Bar-le-Duc to Verdun, known as the *Voie Sacrée* or Sacred Way, was a 50-mile lifeline for the French during the 10-month siege of Verdun. It was at Verdun that General Erich von Falkenhayn convinced the German Kaiser he could bleed the French to death. To understand the importance of Verdun to the French, remember that two-thirds of the whole army passed along it bound for Verdun.[30] As one passes through this picturesque Lorraine region today, various monuments dot the Sacred Way from Verdun to Bar-le-Duc. A sign on one of the monuments indicates that in 9 months 2.4 million men and 1 million tons of munitions were moved down this vital artery. In June 1916, at the peak use of the Sacred Way, more than 12,000 vehicles deployed through it, one vehicle passing through every 14 seconds.

To bleed the French to death at Verdun, the Germans concentrated on logistical support for artillery. They planned to use their heavy guns to blast a hole in the French lines and then send in their infantry.[31] Prior to the first shot fired on 21 February 1916, the Germans had stockpiled 2.5 million shells, some 3,000 for each artillery battery.[32] On the plateau leading up to Verdun, the German Fifth Army built more than 10 railway lines and 24 new stations. Seven spur lines were built in the Spincourt Forest to provision the heavy guns the Germans would put there. The largest German guns were the 422-millimeter mortars or Big Berthas. The shell was as tall as a man and weighed more than a ton. It took 12 wagons to transport one of

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the immense guns and 24 hours to put it together once its destination was reached.[33] A crane was required to load the shell in the gun tube.[34]

The Roads of a Blitzkrieg

In his 1937 book, *Achtung Panzer* (Attention Armor), General Heinz Guderian gave insight into how vital tanks and supporting armor vehicles would be in the conduct of future wars to avoid the attrition of World War I trench warfare.[35] He was the principal architect behind the infamous blitzkrieg strategy.

Guderian was convinced that tanks could not be successful without logistical support. Thus was born the idea of armored divisions to provide the support that allows tanks to fight to their maximum capacity. However, during the creation of the German Armored Force, Guderian's request to motorize heavy artillery battalions was turned down.

Guderian was convinced that tanks could not be successful without logistical support. Thus was born the idea of armored divisions to provide the support that allows tanks to fight to their maximum capacity.[36] However, during the creation of the German Armored Force, Guderian's request to motorize heavy artillery battalions was turned down. In his memoirs, he remarked, "The heavy guns remained horse-drawn, with unfortunate results during the war, particularly in Russia."[37]

The key to the blitzkrieg was the army's ability to be mobile, similar to the vision of De Guibert. Guderian stated, "Only movement brings victory."[38] The emphasis for the tanks was appropriately pushed, but not the logistics infrastructure to support them. As early as 1937, Guderian noted that resupply of Panzers was found to be insufficient during validity exercises. He noted that rapid movement of supplies and repair depots were needed.[39]

During Operation Barbarossa, the invasion of Russia, German logistics was based on *Grosstransportraum* (truck-carrying capability) in which trucks would supply the Panzers. Robert Kershaw, author of *War without Garlands*, described a 500-kilometer logistics tripwire, which indicated the limit of logistics sustainability for the Panzer advance. After 500 kilometers, only rail could ensure acceptable logistics support. However, 500 kilometers was too long; the trucks the Germans used, of which approximately 40 percent were captured French vehicles, were in poor mechanical condition at the outset of Barbarossa. The Panzers rapidly outpaced the foot army, which relied on horse-drawn transport. It was calculated that 1,600 trucks were needed to equal one double-track railway over a 500-kilometer distance. German rail troops had to convert Russian rail to German gauge. After approximately 3 weeks into Barbarossa, 480 kilometers of rail had been completed, but it had only one-tenth the carrying capacity of German rail because of ground structural supports.[40]

During Barbarossa, Guderian and Adolf Hitler spoke of the importance of seizing Moscow because it was "the great Russian road, rail, and communications center."[41] The German Army General Staff anticipated defeating the Russians in 8 to 10 weeks. In Barbarossa, Guderian's center of gravity was the establishment of a decent supply route to resupply his Panzer forces.[42] Unlike Alexander the Great or Napoleon, Guderian could not provision his fighting forces at advance depots using host-nation support.

Additionally, he described the importance of capturing road and rail centers to serve as a base to fight from as the campaign continued. General Guderian stated,

"We could only move as fast as our supply situation would allow."[43] During the advance on Moscow, Guderian said corduroy roads had to be laid down for miles for his troops to be supplied.[44] Grant, 79 years before, had also remarked that corduroy roads had to be laid in order for his army to advance on Corinth, Mississippi.[45] The Third Panzer Division had to be resupplied totally by air. Besides fuel, munitions, clothes, and food, even the salve for the Panzer's telescopic sights did not arrive, which made the tank guns useless. "If only we were mobile and had our old combat strength, then it would be child's play. The Russian is trained and equipped for winter warfare, and we are not."[46]

When Guderian recommended to Hitler that the Germans withdraw from Russia, he was told to dig into the ground where they were and hold every inch of land. Guderian replied that the troops could not dig into the ground because it was frozen to a depth of 5 feet. Hitler then retorted to blast craters with heavy howitzers. Guderian responded that he did not have sufficient explosives even to blast out defensive positions.[47] Lack of a German transportation infrastructure was further exacerbated by the lack of a local area road or rail. Unlike Alexander or Napoleon during his Austrian campaign, the Germans had no host-nation support to secure bases within their adversary's country in which to establish supply depots.

Operational Allied Force and Lessons Learned about Transporting Munitions

In peacetime, the significance of many elements of wartime logistics and administration are not apparent; consequently, officers can be lulled into a false sense of security insofar as these matters are concerned.

—Rear Admiral Henry E. Eccles

The Air Force transformation to an AEF parallels the expeditionary forces of Alexander the Great, the Ottomans, Napoleon, Grant, and Guderian. As with these armies, AEF mobility is dependent on a responsive transportation system or coalition partner to enable rapid transport of warfighting materials. AEF logisticians must be able to respond rapidly to support a mobile combat force in multiple planned and unplanned locations. The AEF involvement in Operation Allied Force clearly showed the criticality of transportation to project airpower—especially in terms of munitions. Moving munitions presents a tremendous challenge to logisticians because of their bulk, wide variety, and the immense quantities required to support modern air operations. Munitions dominated the logistics footprint during Operation Allied Force. Many items can be purchased from a warfighting coalition partner, including large footprint items such as fuel; this is not the case with munitions. During Operation Allied Force, US foreign military sales (FMS) of $35M were generated, mostly in selling munitions to our allies.[48]

At the onset of Operation Allied Force, the United States Air Forces in Europe (USAFE) munitions infrastructure was evolving from a fight-in-place to an

Lack of a German transportation infrastructure was further exacerbated by the lack of a local area road or rail. Unlike Alexander or Napoleon during his Austrian campaign, the Germans had no host-nation support to secure bases within their adversary's country in which to establish supply depots.

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One of the great lessons learned from Operation Allied Force was that a host country's commercial infrastructure, particularly transportation, was the linchpin to US logistics

expeditionary concept. In 1989, USAFE had 57 munitions storage areas and an established fight-in-place operations plan with clear stockpile objectives. By 1999, USAFE had 20 percent of its 1989 stockpile and 24 percent of its 1989 storage capacity spread out in only 14 munitions storage areas. Stockpile guidance was vague, and while the force was still in the drawdown mode, Operation Allied Force provided an opportunity to evaluate the munitions infrastructure necessary to support an air expeditionary air force. In Operation Allied Force, USAFE munitions logisticians projected munitions to nine different locations, had multiple changes in munitions requirements, and coordinated numerous country clearance issues.[49]

One of the great lessons learned from Operation Allied Force was that a host country's commercial infrastructure, particularly transportation, was the linchpin to US logistics in the European Command (EUCOM) area of responsibility. EUCOM is in a coalition warfare scenario and requires the munitions throughput capability that only our allies can provide. On the other hand, Thomas Friedman, in a 3 February 2002 *New York Times* editorial, stated American technology is destroying the North Atlantic Treaty Organization (NATO) alliance. He believes, as a result of being more technologically advanced than its NATO allies, America does not need them to fight a war.[50] Unfortunately, Friedman does not realize how much America relies on the NATO allies' rail and trucking industries to move its munitions.

As Grant pointed out, in referring to the North, "Supplies can be cut off by the whim of the people," so can the whim of our coalition partners hinder or totally cut off our supply lines, which are dependent on the coalition's infrastructure.[51] Flexible transportation is critical because large quantities of munitions must be positioned even though a proportionately small amount will be expended. Target sets and the type of ordnance can change on a daily basis. In Operation Allied Force, 35,000 short tons of munitions were moved, but only 6,000 short tons were actually expended.[52] Munitions accounted for 47 percent of the combat support and sustainment logistics footprint in Operation Allied Force.[53] Integrating commercial and military transportation modes is normal during any munitions move (aside from direct air-force-to-air force airlift). Currently, USAFE evaluates its own infrastructure, such as explosives-sited holding areas or the number of war reserve materiel shipping containers necessary for theater-wide munitions shipments. However, USAFE does not evaluate a host nation's infrastructure throughput for US munitions, even though the critical area is the host nation's transportation of these assets. For example, explosives-licensed, long-haul drivers; security; country clearance; stevedore unions; explosives-sited docks; and explosives-sited rail marshalling areas are unique capabilities for which the United States depends on its host nation for agile combat support. Restrictions such as transportation on weekends, local police rules and regulations, and overland and overflight clearance were different in each country the Air Force dealt with during Operation Allied Force.[54] Additionally, explosives restrictions existed at host-nation seaports, railheads, railways, highways, and the munitions beddown locations.[55]

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When these variables do not exist, logistics workarounds may increase the throughput of needed munitions. For example, during Operation Allied Force, the seaport at Trapani, Sicily, was located adjacent to US aircraft; however, permission was not given to use the port. To supply US aircraft near Trapani with munitions, an air bridge was established using C-130s from Ramstein Air Base, Germany. For 2-1/2 weeks, an average of three C-130s flew in 28 short tons of munitions each day, enabling the wing to carry out its mission until permission was granted to use another seaport sufficient to download munitions.[56] The port finally used was at Empadocle, Sicily, more than a 4-hour drive from the port at Trapani. Additionally, munitions ships were limited to 100,000-poundsnet explosives while berthing at the harbor.

In another instance, the USAFE munitions staff did not anticipate much munitions movement to support B-52s at Royal Air Force (RAF) Fairford, England, because of the 500- and 2,000-pound bombs already at RAF Welford and RAF Lakenheath. However, the B-52s requested 750-pound bombs (M117). The USAFE munitions staff commenced to source 18,000 from the CONUS. Ironically, from 1992 to 1998, the USAFE munitions staff had sent to salvage more than 11,000 M117s that were in the USAFE stockpile.[57]

Additionally, in May 1999, as a result of projected B-52 drops of Mk-82s, the USAFE munitions staff knew they would run out before resupply from the CONUS. The staff worked to move more than 5,000 from US stockpiles in Norway and used them to fill the gap until resupply could be accomplished from CONUS.[58]

Operation Allied Force required a flexible transportation system to swing munitions wherever they were needed on short notice. Munitions forecasting was a challenge in Operation Allied Force; therefore, a robust transportation system that could react quickly to changing munitions needs was necessary. The USAFE Munitions Directorate developed a munitions authorization and allocation plan for every fighter and bomber unit in the theater by using the standard configuration load (SCL) for each aircraft. The SCL was combined with the Crisis Action Operations Center and a target set to develop a validated plan that became the standard for munitions resupply during Operation Allied Force. From this plan, the USAFE Munitions Directorate developed a munitions storage plan for a 5-day munitions requirement for each combat wing. Of the eight operating locations supported with munitions, only three were capable of storing enough munitions to sustain a 5-day requirement by the combat wings at those locations. This meant constant resupply and movement of much ordnance.

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To source munitions, logisticians must have sufficient lead time to coordinate country clearance issues and contract transportation (sealift, airlift, or surface) to ensure the right types of munitions are available for aircraft when they arrive at their forward operating location. In Operation Allied Force, during the anticipated bed down at sites in Turkey, the specific aircraft MDS was not identified until approximately a week out from aircraft arrival. Air-to-air assets were typically flown from Ramstein, whereas laser-guided bomb components (seeker head and tail kit)

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could be either flown in or downloaded from an afloat prepositioning ship in the area.

The potential setbacks at Empadocle, Fairford, and Turkey were offset because Operation Allied Force benefited from working within a theater that had, in most cases, a strong commercial transportation system. Turkish, Italian, Norwegian, British, and German Allies moved 460 railcars, uploaded and downloaded 7 coaster ships, and operated 1,042 transport trucks to deliver munitions to 8 different beddown locations during Operation Allied Force. [59]

Despite the challenges to the movement of munitions, Operation Allied Force was a light challenge to the munitions logistics transportation system: it took 78 days, and 6,600 tons of munitions were expended. During Desert Storm, ten times that amount were expended in less than half the time.

Since the first recorded drop of munitions in 1911 from an Italian airplane over Turkish troops in Libya, the technology of the munitions dropped from airplanes has evolved; however, the 500-pound bomb dropped in World War II is still that, a 500-pound bomb.[60] Technology has improved the accuracy and possibly reduced the quantity of bombs necessary, but the weights have not decreased. During Operation Allied Force, 35 percent of the munitions dropped were precision-guided, compared with 8 percent in Operation Desert Storm. In our present era of precision-guided munitions, the general-purpose 500- and 2,000-pound bombs, standardized in 1941, still weigh the same but now have different tail kits or seeker heads.[61] It is not fair to assess that precision-guided munitions will reduce the munitions footprint. In fact, the containers for the tail kits and seeker heads make the logistics footprint even larger. We may be seeing an increase in killable targets, but the numbers of munitions may not be reduced as first thought.

Despite the challenges to the movement of munitions, Operation Allied Force was a light challenge to the munitions logistics transportation system: it took 78 days, and 6,600 tons of munitions were expended. During Desert Storm, ten times that amount were expended in less than half the time. In Operation Allied Force, the US European Command (USEUCOM) transportation system was not stressed. The Army was not engaged, leaving the Air Force, in most instances, full access to the otherwise Joint-use transportation resources possessed by US Allies.[62]

How USAFE Is Applying Operation Allied Force Lessons Learned

As a result of lessons learned during Operation Allied Force, the USAFE Munitions Directorate created the Theater Munitions Distribution System (TMDS) to create flexibility for munitions distribution by establishing regional munitions hubs in the north, central, and southern regions of the USAFE area of responsibility (AOR). The hubs were chosen because they had the requisite storage, maintenance, and transportation capabilities of the remaining USAFE bases necessary to stage, repair, and swing munitions to any fight worldwide. The hubs are RAF Welford; Ramstein Air Base; and Camp Darby, Italy. The existing munitions infrastructure and storage capabilities at RAF Welford, along with the outstanding civil trucking and seaport capabilities in Great Britain, make it an ideal location. Ramstein directly supports European operations and provides worldwide support through its airlift capability.

Its railhead and truck outload points improve the ability of the United States to stage and move ammunition to and from explosives-sited seaports.

Camp Darby helps support munitions supply for all combat operations south of the Alps. More than half the munitions dropped in Operation Allied Force were shipped from there.[63] It gives the United States tremendous munitions throughput capability and is the only munitions storage area in the entire European AOR with both an explosives-sited water dock and railhead located adjacent to the munitions storage area. The only other US munitions storage area with an explosives-sited seaport adjacent to it is at Kadena Air Base, Japan.

The munitions infrastructure planned under TMDS directly supports Joint movement of munitions. The US Army, Europe would benefit directly from Ramstein and Camp Darby for its mission to project land power through the planned storage, staging, and transportation infrastructure. Likewise, Naval Forces, Europe can take advantage of all munitions hub port improvements to facilitate seapower. NATO coalition forces can enjoy the same benefits as US forces for munitions movements through efficient implementation of foreign military sales.

Finally, TMDS helps minimize host-nation challenges. By regionally positioning munitions, we can minimize the number of country clearance activities during coalition warfare. This also gives us the opportunity to establish modes for munitions transport, enabling US forces to fully inform sovereign nations of planned munitions movements; allows concerns to be voiced prior to potential conflicts; and permits USEUCOM to mitigate national concerns before they become serious. TMDS establishes the means and methods to ensure the success of coalition warfare.[64]

Conclusion

For the Air Force to remain mobile and have a truly expeditionary aerospace force, it must realize that coalition warfare is dependent on our partners, who control stevedores, trucking companies, and rail and seaport networks. It must pay attention to the admonishments of Eccles and De Guibert: officers must not be ignorant of their logistics system. This article does not advocate that leaders and tacticians become logisticians; it advocates that munitions logistics be a key planning factor. In particular, the movement of US munitions, within a host nation or from anywhere on the globe, is contingent on the understanding of host-nation transportation infrastructures and that host nations actually will be transporting US munitions. Coalition warfare is transportation-dependent. The United States cannot perform its mission without considering coalition partners in its agile combat support logistics model. For the foreseeable future, munitions expenditures by US aircraft will dominate any coalition warfare in which the United States participates. In an earlier *Journal* article, "AEF Munitions Availability," the authors stated, "To meet the munitions challenges of EAF, the Air Force must look for ways to improve rapid transportation capabilities, infrastructure, and prepositioning support."[65] Operation

For the Air Force to remain mobile and have a truly expeditionary aerospace force, it must realize that coalition warfare is dependent on our partners, who control stevedores, trucking companies, and rail and seaport networks. It must pay attention to the admonishments of Eccles and De Guibert: officers must not be ignorant of their logistics system.

Transporting Munitions

Enduring Freedom confirmed that the Air Force must heed this advice. As we review the history of a munitions transportation infrastructure, we can focus on one main point—successful military commanders throughout history have concentrated on the transportation of munitions to support the mobility that made their fighting forces successful.

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The Logistics Constant Throughout the Ages

War often conjures pictures of combat and large armies moving to the field inspired by a clash of political ideologies or ambitions. Indeed, the intriguing twists and nuances of the strong political current sweeping every conflict forward or the intricate strategy and battlefield tactics that vie for positional dominance can hold one's attention to the exclusion of all other aspects of war. Yet the bulk of a commander's considerations involve the logistical limitations that drive changes to strategy and tactics in order to keep forces supplied and moving. All manner of logistical supplies are necessary to carry on military operations. However, fuel (fodder for animals or petroleum, oil, and lubricants [POL]) holds a special importance in that its supply has influenced and often dominated strategy as long as nations or states have fielded armies.

Transportation of supplies and materiel preceding modern day machines relied on some form of pack animal, principally horses. The horse's need for fodder dictated to the commander the terrain through which he could campaign as well as the campaign seasons.

Following World War I, new modes of warfare made the use of pack animals obsolete; however, armies still employed them on a much smaller scale to move supplies. Technology—manifested in aircraft and mechanized vehicles birthed in the First World War and nurtured during the interwar period—required a new type of fuel in the form of POL. During World War II, in the European theater, massive armies raced across battlefields, and mechanized equipment greatly increased the spectrum of strategic possibilities. However, commanders still had to account for logistical considerations that would influence their tactics. Increasingly, POL dominated their strategy and tactics. Further, POL products accounted for the majority of supplies shipped into theater during the war.

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Regardless of its modern connotation, POL's intrinsic equivalent throughout history has been fodder.

Military Campaigns, Strategy, and the Need for Fodder

Regardless of its modern connotation, POL's intrinsic equivalent throughout history has been fodder.

Most great commanders in ancient times, such as Alexander the Great, attempted to limit the number of horses on the campaign by ordering the troops and their attendants to carry many of their own supplies.[1] Yet, historian Donald Engels notes that pack animals were still necessary to carry "the army's noncomestible supplies, such as tents, hammocks, medical supplies, the ambulance, siege machinery, firewood, booty, and perhaps some of the women and children."[2] Though Alexander managed to significantly reduce the number of pack animals, Engels estimates that his army probably had about 6,000 cavalry horses and 1,300 baggage animals. Under the most favorable conditions, where the army campaigned in areas abundant in fodder and only needed to carry 1 day's supply of grain, they still needed approximately 1,100 pack animals to carry 269,000 pounds of grain, if each horse carried 250 pounds.[3] Engels notes that if an army traveled through an area devoid of fodder the number of pack animals needed to transport the grain and fodder requirements for 1 day would jump to 8,400 carrying approximately 1,260,000 pounds.[4] Noted historian Martin van Crevald, in *Supplying War*, similarly describes a generic premechanized army in which "the 40,000 animals accompanying an army would, therefore, require 800 acres per day."[5] Horses were imperative in a campaign, yet their subsistence greatly strained an army's resources.

Prior to the 18th century, few improvements were made to ease the fodder supply problem in Europe. In fact, the French made the problem worse by bringing extra men on the campaign to forage for fodder in the army's immediate vicinity. Historian John A. Lynn estimates between "4,000 and 10,000 men [were] necessary to mow forage for an army of 60,000"—each day a horse required approximately 24 pounds of dry fodder.[6] Interestingly, the French did maintain a magazine system to store troop provisions; however, the need to keep moving to find more fodder tended to cause the army to move too far and too fast away from this system of supply.[7] The ever present need to forage for more fodder forced the French Army to constantly move even when strategy dictated that it should not.

Strategy had to be adapted to account for horses' needs. Most historians agree the challenge of providing for the pack animals overshadowed the troops' provisions. Accordingly, the fodder requirement restricted an army's area of operations to regions that could sustain a high fodder intake. During the winter months when cold weather made fodder impossible to secure, armies were unable to campaign, and military operations necessarily became a seasonal activity.[8] Notably, in the 13th century, the Mongols possessed horses that could find food under the snow, so their timeframe for waging war was greatly increased.[9] Early conquerors bypassed cities and only occasionally conducted sieges, as fodder in the immediate area quickly ran out.[10] Intuitively, the massive effort required to forage dictated strict

precautions to prevent being surprised while gathering fodder. Though other factors also influenced strategy, the need for fodder dominated both strategic planning and military operations.

Throughout the first millennium AD, the Muslims were adamant about incorporating knowledge of terrain and vegetation when planning raids. Muslim planners devised contingency plans dependent on the seasons in that, during February and early March, their raids only lasted 20 days so they could get the horses back to Muslim territory to graze. Spring campaigns could only last 30 days, while summer ones were to last 60 because of the availability of fodder.[11] However, the Muslims were also sufficiently organized to set up a series of warehouses near their eastern frontiers over which they campaigned. Reports of these warehouses came in the 7th century and again in the 10th century relating the existence of ready supplies, "including grain and fodder [and] located where defensive or offensive action tended to repeat itself."[12] Despite the Muslims' successes, by the 18th century, few countries, except for the French and Prussians, had adopted a suitable fodder magazine system.[13] The French and Prussian magazine system, as well as the earlier Muslim warehouses, gave their respective forces the advantage of surprise and a greater measure of flexibility by allowing them to mobilize and attack more quickly.

As mentioned earlier, Alexander the Great grappled with the fodder problem throughout his farflung exploits across Europe. Alexander realized the problems posed by bringing along numerous horses and pack animals, so he attempted to minimize their numbers by requiring his men to carry packs.[14] He also understood that excessive work and not enough food would wear out his cavalry and pack animals and he would not be able to nurse them back to health.[15] Welfare for the horses dictated that he slow his army's pace so the horses and pack animals could graze. The need to move faster, therefore, motivated Alexander to look for new ways to reduce his dependency on horses. His massive fleet helped alleviate this problem by transporting large fodder supplies from port to port, though this locked him into a dependency on the Mediterranean coastline or large navigable rivers, especially during winter.[16] The need to provide fodder for his horses forced Alexander to work within increasingly narrow boundaries as he moved farther away from Macedonia. Alexander's campaigns provide one of the earliest recorded examples of logistical handicaps.

As long as armies required horses for cavalry and carrying supplies, the need to find fodder restricted flexibility and operations.

As long as armies required horses for cavalry and carrying supplies, the need to find fodder restricted flexibility and operations. In 1775, during the American Revolutionary War, American forces under General Philip Schuyler planned an invasion of Canada. However, lack of rain made for a hot, dry summer, and General Schuyler could not move up enough fodder to feed the horses needed for a full invasion. Instead, the lack of fodder forced him to wait until late summer when adequate rain nourished the grass enough to supply the invasions.[17] Winter quickly set in after Schuyler experienced early successes and cut him off from all resupply. The "inadequate forage in June and July was not the only reason for the failure of the Canadian campaign, but it surely was one of them."[18]

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The Civil War became the first conflict in which armies used the new technological innovation to improve logistics, especially resupplying fodder, and to alleviate the need to constantly change camps to find more fodder.

Fodder further affected flexibility during the American Revolution when free fodder became hard to obtain and the Colonial Army had to compensate farmers for using their land. Wartime prices steadily rose as good pastureland became less available. However, like Alexander, the American commanders understood that without adequate fodder their limited supply of horses would dwindle. Colonial commanders could send the cavalry away from the army to find cheaper fodder, but they needed the pack animals to stay close and often paid high prices for their nourishment."[19] Without the pack animals, the army could not transport its supplies and conduct operations for very long.

The US Civil War (1861 to 1865) demonstrated the importance of using a rail system to increase strategic flexibility by more efficiently supplying armies. Trains and rail lines came under attack as both sides sought to cripple the other's access to them and prevent valuable supplies from reaching their intended forces. Armies still required cavalry and pack animals to move their food and supplies while in the field and, therefore, continued to need fodder. However, with the locomotive's introduction into warfare, fodder and other supplies could be loaded onto trains and brought to depots within the army's proximity. Established supply lines could then be used to retrieve the materiel. The Civil War became the first conflict in which armies used the new technological innovation to improve logistics, especially resupplying fodder, and to alleviate the need to constantly change camps to find more fodder.[20] In fact, historian James A. Huston, in *The Sinews of War: Army Logistics 1775-1953*, relates that shipments of forage during the winter months averaged $1M. He goes on to say that fodder continued to dominate supply considerations, in that "for tonnage and bulk the item of daily supply that was even more important than food for the men was food for the animals."[21] Trains permitted armies to receive more fodder while maintaining their positions and simultaneously allowed an army to keep more horses.

The period between the Civil War and World War I was filled with advances in technology, which were not fully taken advantage of by the European powers. Further, the dominant powers in Europe (France, Prussia, England, and Russia) failed to truly understand the lessons that could have been learned from the Civil War. Cavalry charges and long baggage trains of horse-drawn wagons persisted, and with that returned the age-old need to feed the livestock. In many ways, the First World War resembled all past wars. However, its rapid consumption of supplies, especially ammunition, dictated that the times and ways of war were changing. But for the moment, it was remarkably similar to the past, in that during the war, Great Britain shipped 5,253,538 tons of ammunition to France as well as the greatest single item shipped, which was 5,438,602 tons of oats and hay.[22] Fuel for horses continued to be a dominant factor.

Regardless of the lessons the Germans should have learned from the past, during World War I, they placed a huge emphasis on cavalry and did not prepare for their maintenance in the field. The German high command ordered commanders to feed

their horses off the land as a result of the army's sheer numbers of horses. Van Crevald relates that any attempt to supply the army from home bases would have been impossible.[23] As the Germans moved into France early in the war, luck appeared to be with them as the land was rich and the grain had just been harvested. However, much of the grain was still green, causing many of the horses to become sick and die very early in the campaign. A critical shortage in fodder resulted, and by the time of the Battle of the Marne, where French and British forces engaged and halted the German advance, most of the horses were too weak to keep up the pace.

The German invasion plan, known as the Schlieffen Plan, depended on the speed of the invasion, yet the horses employed in reconnaissance and pulling the heavy artillery were so poorly fed that they could not keep up the pace. Many died before the Germans crossed the border into Belgium. By 11 August 1914, preceding the Battle of the Marne, cavalry forces ordered a 4-day halt to find food for the mounts.[24] By the Battle of the Marne, the starved horses pulling the German artillery, which was the only arm that had a distinct advantage over French forces, could not keep up the pace. "By this time, too, one German army at least was finding that the state of the cavalry seriously interfered with operations."[25] The German high command's severe lack of oversight of properly feeding the horses proved to be a decisive factor in the failure of the Schlieffen Plan.

Following the offensive stall after the Battle of the Marne, the consumption of supplies reached proportions unmatched by any previous war. However, this consumption rate could not have been maintained if the front had not stalled and remained stationary throughout the war.[26] Supply movement via horses would have been inadequate given the war's immense scale. Toward the end of the war, both sides began to introduce motorized transport on a very small scale and began to argue that "complete motorization of local transportation and the widespread use of combat vehicles would restore mobility to the battlefield."[27] Petroleum products, then, came into demand, and by the war's end, more than 759,000 tons of gas and oil had been shipped onto the Continent. War planners deemed the horse obsolete in favor of the more economical and faster moving petroleum-based machines.

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Military Campaigns, Strategy, and the Need for POL

Following the First World War, armies began nurturing the technological innovations employed at the end of the war and subsequently developed a strong dependency on petroleum products by the beginning of World War II. POL significantly differed from fodder in that POL had to be manufactured away from the battlefield and then shipped to the battle area.[28] For the most part, fodder as a source of fuel for horses quickly became a thing of the past as armies became fully mechanized. The new machines could be worked harder and go farther and faster, and most important, the time of the year and the route taken by the army did not affect its fuel supply. Commanders could expand their range of strategic operations immensely and do more with less.

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However, challenges quickly attached themselves to the new machines and their fuel supply. If army quartermasters did not constantly provide the machines with enough fuel, operators could not normally forage for it. In this respect, commanders lost a measure of flexibility, and the situation forced them to further employ technology to devise ways to overcome the new problems. The result involved underground pipelines and the Red Ball Express, in which a constant stream of trucks traveled distances of up to 400 miles to supply Patton's Third Army.

Following Germany's invasions of Poland and France, POL's role became readily apparent, and Allied strategists sought to cripple the Axis' ability to effectively employ fuel with US entrance into the war.

The beginning of World War II saw the German Army still reliant on horse-drawn transport. Hitler neglected to fully mechanize his transport vehicles, though he dramatically increased the number toward the end of the war.[29] Historian Julian Thompson relates that the Germans only possessed three motor transport regiments, for the whole army, capable of carrying 19,500 tons. In 1944, the Allies in northwest Europe could transport 69,400 tons to support 47 divisions. Thompson goes on to state, "Hitler's failure to build up the necessary capacity to provide the transport essential for mobile warfare was one of the principal reasons for the failure of the German invasion of the Soviet Union (Operation Barbarossa)."[30] Regardless of the German Army's deficit in mechanized transport, the Second World War became the pioneering conflict to be predominantly affected by fuel in the form of POL.

Following Germany's invasions of Poland and France, POL's role became readily apparent, and Allied strategists sought to cripple the Axis' ability to effectively employ fuel with US entrance into the war. Plans got under way to target the Ploesti oilfields in Rumania as strategists estimated that the fields had the capacity to produce 9 million tons of refined oil per year, though it only produced 4 million. Allied strategists understood well the Germans' primitive transportation system and the fact their small fleet of motorized transport vehicles had become extremely overburdened by the war's rapid geographic expansion.[31] Accordingly, the Allies did not attack Ploesti in the hopes of crippling the Axis refining capacity. Instead, they were more interested in destroying Ploesti's refining capability so Germany's limited transportation system would have to move the crude oil from the Ploesti area to other refining sites in Germany or France. The war had already severely taxed the Axis transportation system, and the Allies believed the extra strain would cause supply to other areas to fall apart.

The Allies launched the first Ploesti raid on 1 August 1943 and estimated that the Axis oil supply had been reduced by 3 or 4 percent.[32] It was originally believed the raid had destroyed about 40 percent of 6 months of Rumanian refining capacity or a loss of 1.8 million tons of refining capacity as a result of closing the refining facilities from about 1 week to several months.[33] However, the raid's after-action analysis indicated that Rumanian oilfields possessed twice their estimated production capacity, so subsequent raids would have had to destroy about 3 million more tons of refining capacity to begin really limiting Ploesti's actual refining capacity.[34] Though the mission proved to be successful, the Army Air Forces sustained a 30 percent loss, making a follow-up raid impractical.[35] The Allies moved on to other targets, and the Germans managed to quickly rebuild the facilities.

Evolving into a strategy to attack the entire Axis oil industry, the raid, despite its heavy losses, fueled an intense bombing campaign that managed to strike every major oil refinery in German-controlled territory. Ambitiously, the United States and Great Britain set out to severely damage the German oil industry and keep it subdued. Like Ploesti, the Allies' goal was to reduce the German refining capacity as well as the number of refineries available to cannibalize in order to rebuild larger, more productive refineries.[36] They wanted to present Germany with only two options: transport the crude oil to old unattacked refineries near Marseilles, France, where they were highly vulnerable, or stay in their present locations and attempt to rebuild between raids.[37] The Germans chose the second option, and the Allies timed return missions to prevent refineries from going back on line.[38] As German oil production suffered, so did its armed forces as lack of aviation grade fuel kept the Luftwaffe on the ground and forced the army to heavily dip into rapidly dwindling reserves.

The Germans failed to completely think the entire war effort through and suffered from inadequate fuel reserves. The German Oil Association advised the government that the oil reserves would only last for 5 months given the high rate of consumption. Germany made the reserves last longer by robbing from the civilian sector, but the effects of the Allied bombing after 1943 made the situation critical. Germany's aggressions in 1939 and 1940 were rewarded with its victims' oil reserves. A US investigation following the war relates, "In January 1941, aviation gasoline stocks were approximately 500,000 tons. When Germany conquered the Netherlands, Belgium, and France, about 1 million tons were secured."[39] However, by January 1944, aviation gas had been reduced to 240,000 tons, and by January 1945, it was almost nonexistent.[40] By May 1944, fuel shortages resulted in a drastic reduction in training hours, and operational time was limited strictly to air defenses.[41] The situation had become so critical that the Luftwaffe could provide little opposition to the Allied invasion on 7 June 1944. By 1945, it could not support German ground forces in the Battle of the Bulge after a successful ground offensive.

The Germans failed to completely think the entire war effort through and suffered from inadequate fuel reserves. The German Oil Association advised the government that the oil reserves would only last for 5 months given the high rate of consumption. Germany made the reserves last longer by robbing from the civilian sector, but the effects of the Allied bombing after 1943 made the situation critical.

Germany's lack of fuel reserves also manifested itself in ground operations as the Combined Bomber Offensive and the Allied advance prevented German recuperation. Following victory in North Africa and a successful invasion of Sicily, the Allies drove up the Italian peninsula until stiff German opposition along the Gustav Line halted their advance. The Allies initiated Operation Strangle from 19 March to 10 May 1944 to cut the Germans off from resupply and deplete their fuel reserves. Generally successful, Strangle did not dislodge the Germans, and Operation Diadem got underway on 11 May 1944 to increase German fuel consumption while reducing their resupply through interdiction.[42] Strategically, the Allies planned to dislodge the Germans while strategic bombing would prevent resupply in hopes they would run out of fuel.

Operation Diadem went according to plan, and by mid-May, 14 fuel depots had been critically depleted, and "the mobility of the entire army had been called into

The Logistics Constant Throughout the Ages

Since World War II, POL has become increasingly important to keep an army going in the field. The past 50 years of technological advance have only optimized modes of transportation, not lessened the impact of fuel on strategy, tactics, and operations.

question."[43] German fuel was adequate to compensate for the defensive maneuvers necessitated by the Allied advance at the beginning of the operation. Yet, by early June, the effects of the campaign presented a very hard reality. The German armies had been in retreat for a week, and the American Fifth Army presented a constant threat.[44] Though this defense suited the mountainous terrain and the situation, it required a lot of fuel that the army did not possess. "By June 6, the army was making its moves piecemeal—a unit would move, exhaust its fuel, and wait for resupply."[45] Defensive maneuvers, the mountainous terrain, and movement at night saved the German Army from total defeat, but fuel's use in strategy and its subsequent effect on German strategy was enormous.

On 6 June 1944, the Allies launched Operation Overlord, and the invasion of Eastern Europe began. Original plans called for the Allies to steadily push the German Army toward the Rhine and then force surrender. However, after a massive aerial bombardment on 25 July, the Allies forced a gap in the German lines and then exploited it by pouring through armored divisions.[46] New tactical opportunities to quickly defeat the Germans presented themselves instead of the originally planned methodical push to the Rhine."[47] Patton's Third Army raced through southern France consuming an average of 350,000 gallons of fuel each day.[48] By 7 August, the Third Army had exhausted its fuel reserves, though it managed to maintain the rapid advance for another 3 weeks. Fuel supply reached critical levels from 20 to 26 August when both the First and Third Armies, pursuing the retreating German Army, consumed an average of more than 800,000 gallons of gas a day.[49] However, the supply lines had not yet become so long as to be unmanageable by theater logisticians, and the Allies had enough fuel to enter Paris on 24 August.

Pre-invasion planning called for the Allies to halt and wait for the logistical network of communications and food pipelines. However, their shipping successes and rapid advances into Paris with little German resistance called for a reevaluation of the plan. General Bradley, commanding the First Army, was quoted as saying, "Armies will go as far as practical and then wait until the supply system in [the] rear will permit further advance."[50] Basically, he proposed to move forward, taking as much ground as possible, until they ran out of gas. Once again, fuel requirements dominated strategic decisions and operational action.

Since World War II, POL has become increasingly important to keep an army going in the field. The past 50 years of technological advance have only optimized modes of transportation, not lessened the impact of fuel on strategy, tactics, and operations. While technological advances may reduce the amount of support equipment required for military operations and the size, lethality, or amount of munitions—all of which will further reduce lift requirements—similar advance is seen as unlikely for fuel. Arguably, fuel will remain the dominant logistics factor that limits strategic and tactical planning as well as actual operations for the foreseeable future.

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Colonel Logan "Jay" Bennett, USAF, Retired

Murphy's Law

Colonel Crawford O. Murphy was my boss for 1 very remarkable year in the late 1970s. I was in a very comfortable assignment at the Military Personnel Center, Randolph AFB, Texas, but chose to go to Osan AB, Korea, for my second remote assignment in 15 years. About a month before departing, I received my first correspondence from the unit's deputy commander for maintenance (DCM), Colonel Murphy. It was a handwritten note stating, "Don't bring your golf clubs; we don't have time for it here." I'd heard all sorts of stories about this intrepid character (most recently from a friend, Major Luke Gill, who had arrived at Osan AB months earlier), so my anxiety was heightened with this caustic note. In the next 12 months, I was to receive many of these notes.

My assignment, on paper, was to command the component repair squadron (CRS). However, when I arrived, the departure of several field grade officers meant the maintenance control officer, CRS commander, aircraft generation squadron (AGS) commander, and quality control (QC) jobs were all up for grabs. Murphy wanted time to evaluate the possible replacements before selecting them. He insisted that departing incumbents remain in place until the very end of the month they were eligible to return from overseas. (All incoming field grade officers arrived at the beginning of the month. A year later, they left Osan at the end of the month, making this nearly a 13-month tour of duty, a Murphy policy.)

Colonel Murphy interviewed all senior noncommissioned officers (NCO) and officers one-on-one within days of their arrival. This interview was strictly a one-way conversation. Here's the nature of my interview, as I've kept my notes over the years and used them myself.

- Be happy and aggressive.
- Know the *-6*.
- The squadron maintenance supervisor runs maintenance.

Murphy's Law

- Production belongs to the senior NCOs, not the officers.
- Identify weak people and press them to become stronger.
- Don't accept anything short of perfection.
- No battles, period.
- Quality assurance (QA) reports are to be answered with what we're doing to correct the problem.
- Know at what level decisions should be made and hold those people responsible.

It always began at 0430 (except for Sunday) with a phone call to my quarters. I was usually in the shower at that time and kept a close ear for the ring. It was Colonel Murphy. "Good morning, are you the commander of the Animal Gathering Society (sometimes it was the All Girl Squadron)?" This was followed by a long pause. "Major, why aren't your crew chiefs getting their paychecks on time?" Or, "Why do your crew chiefs need haircuts?" Or, "When are you going to insist on clean forms on your airplanes?"

In about 2 weeks, Murphy made his decision on assignments, and I was extremely fortunate to be selected to command the AGS, replacing the extremely popular and very competent Major Dick Rose.

In those days, Osan (51st Composite Wing) had 24 F-4Es, 16 OV-10s, and a full-time detachment of 6 RF-4Cs. The maintenance organization was an early production-oriented maintenance organization (POMO), with a DCM—Colonel Murphy, also known as *Alpha One*. While the tour of duty was nearly 13 months for most of us, certain key staff members served longer tours (Murphy served for 3 years).

My memory is very clear about those events 22 years ago, serving as AGS commander under Alpha One, and I would like to share some of those experiences with you.

Permit me to describe a standard day. It always began at 0430 (except for Sunday) with a phone call to my quarters. I was usually in the shower at that time and kept a close ear for the ring. It was Colonel Murphy. "Good morning, are you the commander of the *Animal Gathering Society* (sometimes it was the *All Girl Squadron*)?" This was followed by a long pause. "Major, why aren't your crew chiefs getting their paychecks on time?" Or, "Why do your crew chiefs need haircuts?" Or, "When are you going to insist on clean forms on your airplanes?" Then, before I could answer, he would hang up. After a few of these calls, I became very annoyed, with him and with my inability to anticipate his daily questions. It soon became apparent that Alpha One cruised the flight line every morning from 0300 on, searching out *his people*, my crew chiefs. After several weeks of this, I eventually got used to it and followed up during the day, unless it was an airplane problem, which I investigated before I left my quarters in the morning.

I always stopped by job control before starting my rounds. Murphy's job control was unique, as were his expectations. Every decision that could be moved from job control to the flight line was, letting the AGS expediter work the problem through the specialist supervisors on the line and work out a course of action. Job control was to let that course of action stand unless they could prove it impacted future schedules—or other priorities to the on-scene bosses—to prepare aircraft to fly. Job control should keep reminding the flight line of considerations, and they should obtain the help on-scene bosses needed. Colonel Murphy considered the AGS expediter the orchestrator of the ongoing maintenance effort. He spent lots of time needling the specialist dispatchers for failing to keep the workforce occupied when there was something productive they could be doing, such as dispatching avionics

specialists to clear delayed discrepancies. He never let the shop chiefs forget they were the ones who should be bugging job control for an airframe or to do what needed to be done.

After establishing how the schedule was being met for the day, I usually visited each shelter that housed an aircraft on the day's flying schedule. Over time, you could tell just by looking at the activity (or listening to the radio) whether the bird was coming together or not. It was especially nice to have fewer than 50 airplanes—knowing tail numbers, locations, names of the crew chiefs, and the aircrafts' history wasn't difficult.

Colonel Murphy's reputation, integrity, and work ethic centered on scheduling. With 27 F-4Es authorized and 24 or so on station (2 or 3 were often at programmed depot maintenance), his ironclad policy was to keep half of them on the ground for scheduled, unscheduled, and delayed maintenance; time compliance technical orders; washes; paint; weapons load training; and so forth. He forbade any tail number *swapping,* with the policy concurrence of the deputy commander for operations and the wing commander. In short, if aircraft 421 was scheduled to fly on Monday, Tuesday, and Thursday, it damn well flew on those days. No one substituted one airplane for another, or they would have been fired. Case closed. If the wing commander took aircraft 551 to Kunsan for a conference on Monday and returned that evening with it out of commission, it was not substituted if it wasn't able to fly as scheduled on Tuesday. That's what spares were for. On a typical day, using 11 jets, the schedule called for 9 + 3; that is, 8 + 3 spares on the first go. The turn was a diminishing rate, 8 + 4, then 7 + 5, and so on. I recall, quite early one morning when driving down B-ramp, seeing two crew chiefs scuffling in front of a shelter. I broke it up and asked why they were fighting. Colonel Murphy had been by that morning and said the crew chief of the aircraft flying the most sorties that day would get something special from him (probably a six-pack if memory serves me.) The scuffle broke out because one crew chief's airplane was a spare that day and he was being teased by the other guy because the spare would never be flown and was thus ineligible for the Alpha One *special.*

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Combat turnarounds occurred almost every day. A special location was set up where returning jets were *combat turned*, engines running, weapons loading, refueling (engines were shut down), and overall servicing, including the through-flight inspection. We often *turned* aircraft in less than 30 minutes. Given the scheduling scenario of a diminishing number of follow-on sorties with each turn, there were always plenty of airplanes available, mainly because of the discipline Murphy had established for scheduled maintenance on nonfly days. That was the key to his extraordinary success. (From July 1978 to July 1979, the wing had an astonishing 1.02 sortie rate for the F-4E.) I cannot emphasize enough the discipline that made this system work. No one changed the weekly schedule, where tail number assignments were published. It was common at the end of the flying day to have airplanes fully mission capable and no pilots to fly them. There were no exceptions

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to the *no change* policy unless we had an operational readiness evaluation or operational readiness inspection (ORI), and obviously, the wing then had to generate *all* aircraft.

Perhaps now would be an appropriate time to share an event that occurred on 9 November 1978 during an ORI. At about 1700, following an especially tough flying day (one F-4 needed an engine change, and one had a serious fuel leak), the Pacific Air Forces (PACAF) ORI team landed after holding on final for an F-4 to be removed from the barrier. The senior maintenance inspector, Lieutenant Colonel Harry Blue, went directly to job control where the commanders and maintenance supervisors were assembled. Harry walked in, checked the status, got the *brief* from the maintenance control officer, and commented to me when he walked out, "You'll never make it." We had 24 F4-Es and about 15 OV-10s, and no one knew how many RF-4Cs Kadena would send us. Of the F-4s, five were in very serious shape, including one in phase and one in phase prep, besides the two with major problems mentioned above. We needed to generate all 24 F-4s in 12 hours, or by 0500 the next morning, to get the top rating. We returned to our squadrons, established the shifts, and subconsciously fretted over how in the *Sam Hill* we would get it done. Murphy always went to the officers club for dinner at about 1800. Always. There was a special maintenance table at the club in those days that sat about a dozen people. The head seat was Alpha One's. No one else sat in that seat, unless it was a tourist (upon which Murphy would exit the club and go to his quarters). That infamous night, Murphy went to the club as usual, ate alone (the rest of us were sweating bricks on the flight line), and then went to his quarters on the hill. All night, we watched the activity on the line, and one by one, the jets came together. Murphy showed up at about 0400, just in time to watch the last of the engine changes—the engine run and the preflight completed about 5 minutes before the 12-hour generation expired. All 24 F-4s, OV-10s, and RF-4Cs were in-commission and preflighted. The ORI report read in part:

> The professionalism displayed throughout the maintenance complex was the best observed in PACAF.… "Excellent" rating for the DCM complex … and, "highly commendable" on the unit's miraculous recovery from severely degraded maintenance following an especially tough flying period.

Months later, during a rare post-dinner exchange with Alpha One, I asked him about that evening. "Colonel, during the most important period of time during our assignment here at Osan, you were in your quarters. I don't understand." His comment was enlightening, "Jay, I spent months preparing you and the other members of my team to go to war. My goal was to put you all in a position to lead the effort, and you did. I wasn't needed, and my presence would have had a negative impact on your efforts."

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Aside from the normal, day-to-day activities of a flying unit, our role as commanders was to deal with our people and their problems, with an unrelenting eye (and ear) on generating airplanes. Not that we had to have the job control net in

our office (we didn't), but our maintenance supervisors were always keeping us informed. Murphy made it very clear to all of us that *production* meant senior NCOs and *management* meant officers. The real power belonged to the E-6/E-7 line chiefs and our superintendents. The officers provided the wherewithal for them to do their job.

Which brings me to the subject of meetings under Alpha One. He believed big meetings with lots of people invited decisions to be made at too high a level. He felt that hardly ever in a meeting atmosphere does the DCM make a decision that couldn't be made better by someone below him. He also said that because the boss in those circumstances seldom had enough information to make the right decision the decisions made were "usually unmade by sundown." He believed the DCM should do only those things that only he could do. For example, he thought it was most absurd to have people call him to get approval for cannibalizations. Most of the decisions traditionally reserved for DCMs were, in his view, inappropriate because they were decisions dealing with the minutiae of executing plans, programs, or schedules. Murphy decided, with advice, how many sorties to fly in a period and what patterns to use in scheduling. He would set the policy on what types of things to cann or what types of missions to support. That would allow others to make the right decisions on each occasion. So what about his meetings? There was only one, the *Seventeen-ten* (1710). The meeting was called by the noncommissioned officer in charge (NCOIC), Deficiency Analysis (an E-7) whenever there was a deviation from the day's flying schedule (air abort, ground abort, maintenance nondelivery). It didn't matter if it was triggered by a deviation at 1700 that day or 0730, and if there wasn't a deviation, there was no 1710. Each commander; maintenance supervisor; complex superintendent (a chief); QC officer; maintenance control officer; job control officer; and NCOIC, Deficiency Analysis showed up in Murphy's small office. There weren't enough seats, so one person stood (usually Captain "Bubba" Parker, my maintenance supervisor). The meeting began promptly at 1710. Murphy wanted the entire wing complex, most of whom had gone to their quarters by then, to know that the DCM complex was on *point*. The NCOIC, Deficiency Analysis opened the meeting by saying something like, "Aircraft 330 had a ground abort for a leaking brake," upon which Murphy would look right at me with hawklike eyes and ask why. Bubba would tell him the brakes had been changed in phase the day before, and Murphy would look at Luke and ask why. Captain Steve Smitherman, the Equipment Maintenance Squadron maintenance supervisor, would say, "Sir, the brake stack was installed backwards and Airman so-and-so was unsupervised, and Staff Sergeant Smith or Jones failed to do an IPI." Murphy would then look to the QC manager (Major Rich Romer) and ask why QC didn't catch it. Sometimes this dialog would last half an hour on each deviation until he was satisfied the root causes were discovered. Days with more than one deviation often had the 1710 go way past 1830. After deviations were discussed, every repeat and recurring writeup written since the last 1710 meeting was discussed. Sometimes,

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Murphy's Law

Dirty airplanes were not acceptable, and had Murphy found one to be unacceptable, I would catch hell. That included faded paint or greasy fingerprints on access panels. The crew chiefs knew it, too, as they were pampered by Alpha One almost to the point of fraternization. He knew them all by name, often their backgrounds and individual personalities.

we hashed over scores of these with the same dissecting inquiry used on the deviations. At least we had time to prepare for these. I recall never going more than a couple of days without a 1710 that year with mixed emotions, because if we had, it would have allowed a lot of repeat or recurring writeups to pile up.

After the 1710, most of us returned to our offices to wrap up the day and make sure the swing shift course was set. Then off to dinner at the officers club, where we would probably find Alpha One finishing his meal and others in various stages of dinner. The dinner period was enjoyable—not a lot of shoptalk—rather, poking fun at each other and once in awhile taking a fun shot at Colonel Murphy.

Once during our tour, each officer was invited to Murphy's quarters for homemade soup. That was a very special occasion, and surely, all of us have special memories of that event. The setting was a little awkward given the circumstances—a bachelor colonel's quarters—with classical music. The soup was superb. The evening lasted about 90 minutes, and then it was time to go. No shoptalk, just listening to him read some favorite poems or inquiries about our family and life.

Saturdays were like every other day for the most part, occasionally with only half a day flying. We never flew on Sunday. I used Sundays to spend quiet time with each airplane, without any company, to review the forms and evaluate the overall condition of the airplane. Dirty airplanes were not acceptable, and had Murphy found one to be unacceptable, I would catch hell. That included faded paint or greasy fingerprints on access panels. The crew chiefs knew it, too, as they were pampered by Alpha One almost to the point of fraternization. He knew them all by name, often their backgrounds and individual personalities. I recall the image of a crew chief leaning in the open window of Murphy's pickup truck at 0500 or 1000 or 1430, joking with their big boss. He loved those crew chiefs. He often had lunch with them in the flight-line cafeteria, a facility that he insisted on having near the troops.

I saw Colonel Murphy cry one time, and I hope he forgives me for bringing it up, but it shows the compassionate side of this special person. One of his favorite crew chiefs was a staff sergeant who was on his third year at Osan. He was married to a Korean national and was also one of the most respected mechanics in the complex. This sergeant was indicted for black marketing activities (he sold a washing machine to a Korean). When Colonel Murphy learned of this, he cried like a baby. He was devastated. Murphy spoke on his behalf at the court martial in emotionally muted tones you could barely hear in the courtroom.

There are, of course, far too many memories to capture in this narrative about Alpha One. Each one of us was pushed to our full potential, and in my case, I carried his intensity and focus on to greater challenges in subsequent assignments. It became natural in the years following Osan, when faced with problems and decisions, to find the clear and correct course of action using the foundation provided by him. He was outspoken and light-years ahead of his time, but his focus was always the same. In my later active duty and Boeing years, some of my decisions were challenged

Murphy's Law

and criticized, often by government agencies with a different agenda, but my bottom line was always a clear conscience with the knowledge that I had done the right thing. I owe that to Crawford O. Murphy.

Some of us stayed in touch with our old boss over the years. He retired in the early 1980s and returned to his birthplace and home in Cambridge, Maryland. There he was affectionately known as Neal. I visited him twice and found him to be very happy and comfortable. He remained a bit curt and always the disciplinarian but very modest and full of life. He passed away in the early 1990s.

Crawford Murphy should have been promoted again. He made colonel in less than 15 years, as a nonrated maintenance officer. His downside, I am told, was his impatience with higher headquarters and the reorganization of aircraft maintenance that was occurring in the Air Force. His attitude on that was unacceptable to his superiors, but he, nevertheless, voiced his objections at every opportunity. His messages were infamous. One I will never forget was known as the *Shah of Iran* message. It started out in a message to Third Air Force and PACAF. "I feel quite certain that the Shah of Iran thought the only obstacles to his program were some older supervisors who were resisting change." He then went on to outline two major logistics initiatives (POMO and centralized intermediate repair facility [CIRF]) in PACAF that he felt were detrimental to "flying plenty of safe and effective sorties," his motto. He believed the idea of a self-sufficient aircraft maintenance unit (AMU), the heart of POMO, was an appealing idea. However, he also felt it took far more fully qualified and experienced technicians than we could afford, working in a more stable environment than we could provide. Additionally, he felt that the specialists, under POMO, were fragmented and that led to instability. Constantly moving and borrowing specialists between shops and other AMUs turned out to be an unsupervised nightmare and led to poor quality work. He also believed the quality of troubleshooting was reduced under POMO because complete malfunction histories were not readily available to supervisors. Finally, he believed qualified supervision was seriously reduced, primarily because the system would not provide the smaller work centers with the higher NCO grades previously authorized in the larger organizations.

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Crawford Murphy worked with CIRF for 3 years. He didn't believe it enhanced our combat capability in Korea; he felt CIRF degraded it. Remember, he was managing F-4 and OV-10 aircraft with considerable intermediate-level maintenance requirements. The loss of a reparable asset out of the base-level maintenance system was unacceptable. He also felt that airlift, absolutely critical to a functioning CIRF, made the whole process extremely vulnerable in wartime. The loss of the base-level pipeline, from shop to flight line to supply, was simply unacceptable. His arguments continued with challenges to the economics of the system, the increased damages to avionics line replaceable units, and loss of the capability to rapidly fix bad boxes during wartime.

Murphy's Law

In his end-of-tour report, he credited the "unparalleled cooperation of the aircrews and their bosses … who willingly did the mission in a fashion that provided us the best chance of success regardless of their personal druthers."

Some Murphyisms:[1]

- Commanders are supposed to command—maintenance control officers are supposed to stay in maintenance control and not bother anybody.
- Maintenance control officers are not supposed to be out on the flight line—that is squadron business, not maintenance control business.
- First of all, it's [maintenance] going to have one boss—me. I will not ask and do not expect either my assistant, my maintenance control officer, or my squadron commanders to set maintenance policy. I want one clear source of policy—me. However, I want my commanders to command. I do not want my staff to interfere in that command.
- The single most important thing controllable at wing level that will advance the sortie-production goal is to follow the weekly flying schedule. Once it has been decided which aircraft will fly on which days, do not change it. If you think just a few changes will be acceptable, you are wrong. When your people realize they can count on the schedule about as well as a sunrise, you can be sure they will fight to fly that schedule.
- I hear officers shy away from field assignments because the risks are high, exposure low, and the work hard and less forgiving. Base-level jobs were, in my opinion, the most difficult—and for me the most rewarding—and they were the ones where the rubber meets the road and the flying and fighting are done.
- Probably the most frustrating job is being my maintenance control officer. Most maintenance control officers think they control maintenance. I don't want that. I want him to coordinate all operations staff and supply matters and coordinate maintenance schedules. The NCOs on the flight line do a marvelous job controlling maintenance and do not need lots of direction. There is no need for directions from job control, just information and outside support.
- I expect being my assistant DCM must be a frustrating affair. I always instruct my assistant to not give any instructions or directions to maintenance people about the job of maintaining aircraft. I never ask him to catch the overflow and do things that I don't have time to do. The assistant is responsible for civil engineering programming, manpower changes, communications, budget, programs and plans, and training. He is in charge of ORI procedures and maintenance manning in the command post during exercises and preparing nominations for unit and individual awards. Two areas that make me the most money are his actions in manpower and civil engineering matters. No one is usually working those areas daily to get results; he does and gets results.
- I think all squadron commanders who work for me would agree there really are only a few things that I insist be done my way. They have more decisionmaking power than any maintenance squadron commander I know. One of my favorite

answers to a question is, "I don't plan to answer that—you do what you want to do." If I think they made a dumb decision, I tell them, but I don't pull the decision up to my desk when they make a dumb one.

- I ask commanders to tell me why we have holes in the schedule and what they are doing to prevent it from happening again. It is useless to discuss preventive action unless you know who did what wrong. Only then can you find out why it is done wrong, identify the cause, and develop a good corrective action.
- Insist that your people be aggressive supervisors. Ask them to do the maximum, not the minimum acceptable. If they are the type person who will do only those things that, if left undone, you could prove they should have done, then they are meeting the standard. To be outstanding, they must do the things their bosses wouldn't even know they had the opportunity to do until they saw it done.
- I warn incoming supervisors they have two tasks anytime they receive a QA report: one, identify deficiencies and, two, do not debate the validity of the report. Once the report is written, the owner of the deficiency needs to fix the problem and prevent it from recurring as best he can. Reporting deficiencies is not a happy business. I want a ranking officer in QA. Only my assistant and I outrank him. Each morning before 0700, I have my QA officer bring me the results of the on-aircraft inspections of the last 24 hours. I want to be in a position to mention success and failure to those responsible as I visit them during the day. I see all QA reports when they have been completed to show cause and corrective action and preventive action. Most failures of QC control inspections are directly attributable to first-line supervisors; either they did not teach the failed technician how to do the job, or they did not insist that the technician do the job he was trained and directed to do.

Notes

1. Taken in part from "Compendium of Things," authored by Colonel Murphy, and sent to me in 1979.

Section Two

Contemporary Thought and Issues

Wing Commander David J. Foster, RAF

Fightn' N' Stuff

I git thar fustest with the mostest men.[1]

—Lieutenant General Nathan Bedford Forrest

To win in battle we must concentrate combat power in time and space. Strategy and tactics are concerned with the questions of what time and what place; these are the ends, not the means. The means of victory is concentration and that process is our focus here. There are only four key factors to think about if we seek success in concentration. This is not a simple task. Although few in number, their impact, dynamics, and interdependencies are hard to grasp. This is a problem as much of perspective as of substance. It concerns the way we think, as much as what we are looking at. The factors are not functions, objects or even processes. They are best regarded as conditions representing the nature of what we are dealing with in seeking concentration. They are:

Variability - Uncertainty - Synchronicity - Complexity

In this analysis we take a systems view of the world to look at basic concepts, to arrive at a way of looking at things, rather than to present a set of answers. The ideas are fuzzy, so we use simple words and pictures. Simple words like *stuff*. This means fuel and spares . . . bullets, bombs and missiles . . . tools, machines, power and water . . . food, maps and toilet paper . . . and anything else we need to keep us in the fight. The use of simple language is not a trivialisation; it forces us to focus on essentials. One of the problems we face is the way we think. Here we attempt to look at things from a new angle, to break out of the old frame of reference, to think out of the box, to reflect on the basics.

In the widest sense of the term, which is how we will use it, logistics is the crucial enabler for operations. However, logistics on its own is not worth talking about. It is not independent. It exists only as one half of a partnership that governs the success

or failure of concentration. Our aim here is to develop a simple, holistic description of the partnership of operations and logistics, to provide a perspective for effective thought and action.

First, we explore the fundamental nature of the partnership. We start at the point where operations and logistics meet, then step down into the world of stuff to take a look at what happens there. Once we have a picture of the basic mechanics of logistics we move on to look at what links activity in the world of operations to work in the world of stuff. We then use our new perspective to examine how the particular nature of a military force governs the way things happen in practice. Here we look at the differences and similarities in the structure and dynamics of the partnership in the separate cases of land, maritime and airpower, to determine how the partnership works. In conclusion, we offer a view of what really matters in managing the partnership to achieve our goal of effective concentration.

Why is understanding this so important? Logistics governs the tempo and power of operations—for us and for our enemy. We have to think about the partnership of operations and logistics because it is a target. A target for us, and for our enemy. Like any target, we need to fully understand its importance, vulnerabilities and critical elements to make sure we know what to defend and what to attack. All military commanders, at all levels of command, rely on the success of this partnership. How well they understand it will make a big difference concerning how well it works for them and how well they work for it.

Logistics gives operations the stuff needed to bring a weapon to readiness. Stuff includes fuel and things that go bang, but also serviceable parts for the weapon and personal kits for its operators. Lack of stuff usually gets the most attention; it is what makes the most noise, where the pain seems to come from, where failure first becomes apparent.

> *A real knowledge of supply and movement factors must be the basis of every leader's plan; only then can he know how and when to take risks with those factors, and battles are won only by taking risks.*
>
> **—Field Marshall A. C. P. Wavell**

Real knowledge in this context is deep knowledge, not simply how long it takes a force to move from A to B, or the numbers of weapons needed to take on a particular enemy strength; but an understanding of the likely behaviour and response of the logistics system, in the face of the real demands, of real operations, as they develop and as they are executed. So this is a tale of two systems and how they work together as one: operations and logistics—*Fightn' N'Stuff*.

Part One—The Nature of Fightn' N' Stuff

Operations and logistics sit alongside each other; they overlap (Figure 1). Imagine the overlap as the area where fighting machines are loaded before launch and recovered after an engagement. Between the two systems there is an interface where information and objects are exchanged, in both directions. This *communication* takes time and energy. Logistics gives operations the stuff needed to bring a weapon to readiness. Stuff includes fuel and things that go bang, but also serviceable parts for the weapon and personal kits for its operators. Lack of stuff usually gets the

most attention; it is what makes the most noise, where the pain seems to come from, where failure first becomes apparent. But often it is not where we find the real cause of failure; lack of stuff is the symptom, not the disease.

Logistics gives operations information. We sometimes overlook the importance of getting this right, and then we fail. To be effective, operational planning must have a good indication of how the logistics system is likely to perform under load. But operators are not mind readers, they have to be told what can and cannot be done.

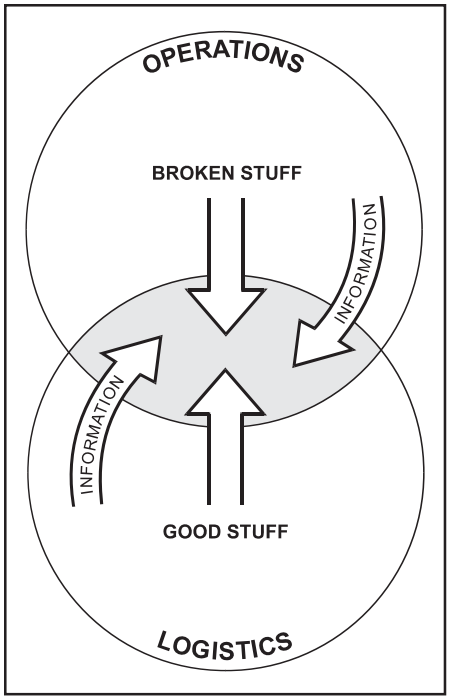

Figure 1. Operations and Logistics

Even less well understood is how much our success depends on operations getting stuff and information back to logistics. Firstly, a lot of stuff is scarce and critical. Broken stuff of this kind is a potential resource. The quicker we mend it and get it back into circulation the higher our readiness states will be. Consider the priority given to operational turnarounds to get an aircraft fuelled and armed and back on-line for the next mission. The same urgency is needed in regenerating critical aircraft components, for exactly the same reasons. Secondly, logistics needs information. Some of our stuff runs out of life and some we break. Some stuff we consume, like fuel. Timely and accurate information on actual and potential usage, in terms of breakage, failure and consumption, is important. Without this feedback on changing circumstances the logistics system cannot respond and adapt and support performance will deteriorate.

Now we have a simple view of the key *transactions* between operations and logistics. But what happens inside the two systems? What drives the transactions? Our next step is to take a close look at the world of stuff.

To get answers, we need to look at logistics as a complete system, and we need to stand well back to get the whole picture. We need to think about: what the system is for, what it includes, what it produces, what happens inside it and what is needed to feed it, how it is put together, what it handles and how it works. The fundamental purpose of logistics in our context is to enable the focusing of combat power, in time and space. That is what it is for, but what is it? This analysis proposes that we can see it as just a few very simple processes (Figure 2).[2]

Logistics gives operations information. We sometimes overlook the importance of getting this right, and then we fail. To be effective, operational planning must have a good indication of how the logistics system is likely to perform under load. But operators are not mind readers, they have to be told what can and cannot be done.

Fightn' N' Stuff

What makes logistics such a puzzle is that we put hundreds of these simple processes into a complex network of relationships and then populate the network with thousands of families of components, subsystems and parts all moving around the network from one simple process to another, sharing pathways, hitting bottlenecks and waiting.

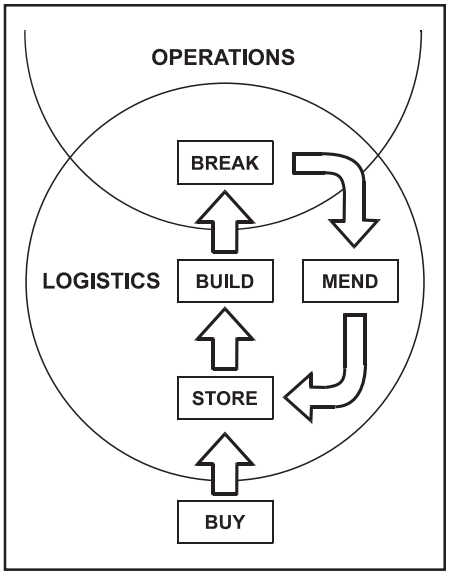

Figure 2. Processes

Clearly, before we can do anything we have to bring new stuff into the system from outside: we BUY. This is a fundamental process, but we are concerned in this discussion with the problems of fighting with the stuff we have already got our hands on. We will not consider here the planning, budgeting and programming issues, the *shopping* problems, important though they are.

What do we do with stuff once we have it? We MOVE it around the system. When it is not moving we STORE it. This all takes people, facilities, transport, management, and time. We MEND stuff we have broken and stuff that fails. This takes skills, tools and spare parts, and time. And for complex stuff each different piece usually needs its own very specific skills, tools, and test equipment. We put stuff together to BUILD more complicated stuff. Again this takes skills, tools, and equipment that are specific to the task and more time. Each process is very simple. It is true that within the MEND box we find very skilled and intricate engineering activity, but in essence all that clever work does is generate more demands for more stuff. It is tempting to identify a separate process showing us REPLACING stuff we have consumed, but this is merely a special case of the general cycle. When we consume stuff the flow is only one way. There is one caveat. Figure 2 shows operations as the only source of broken stuff. This is just a schematic simplification. Stuff also breaks and is consumed in the logistics system.

These are simple processes. What makes logistics such a puzzle is that we put hundreds of these simple processes into a complex network of relationships and then populate the network with thousands of families of components, subsystems and parts all moving around the network from one simple process to another, sharing pathways, hitting bottlenecks and waiting. Waiting for parts to arrive to complete a set and fill the last hole in a component. Waiting for repair facilities to be free.

Consider what this means, at each stage. First we have to find all the parts we need and get them together in one place. Then we have to put them together as a set. This takes time, tools and skill.

Only when the last part arrives and is fitted, when the last hole is filled, can we move on to the next stage. And we do not know what will arrive last and how long it will take. Building creates delays, and they add up. For an individual part, no

journey through the network will be like any other. This fact is simply a result of the complexity and interdependence of the network itself. Delay in the time taken by one process will add to the delays in processes further down stream. The resulting variability[3] in how long things take to do is a fundamental condition of any logistics system. Once we start dealing with the assembly of complex mechanical and electronic stuff, and the test and repair of components, we enter a world of probability distributions and queuing. It is like going for a haircut, having a car serviced or buying a stamp in the post office. We cannot rely on a precise schedule. How long it takes all depends on who else wants to do the same thing at the same time.

This is important and bears emphasis. Logistics is made up of very simple processes, but these are arranged in a network of interdependencies that, when acting on the many different units of stuff that are needed to support each weapon, create a complex, busy, dynamic system full of variability (the first of our four key factors). To be successful this system must respond to the demands caused by activity in the operations system; not just what is wanted now, but what may be wanted later; not just what is wanted by operations, but what is wanted by parts of the logistic system to complete work needed to continue productive throughput. This leads us to the second key factor.

How and when demands will emerge is a source of uncertainty for the logistics system. We do not know what will fail next, nor exactly when. This is the core problem for the partnership. We want continuous forward motion; to get this we seek certainty and speed, however, because of the very nature of logistics, we face uncertainty and delay. The crucial question is: how can we organise a logistic system to meet these demands effectively, when we know that the time taken to do things in any logistic system will always be variable?

A good way to understand a process is to start with the end product and work backwards; in this context we need to stand at the front line of the world of operations and look to the rear (Figure 3). In simple terms, the final output from operations is an engagement, where a target is hit. To do this we have to concentrate combat power in time and space and this requires weapon systems loaded and fit to fight. This point of readiness is where operations and logistics touch. Notice that, in the

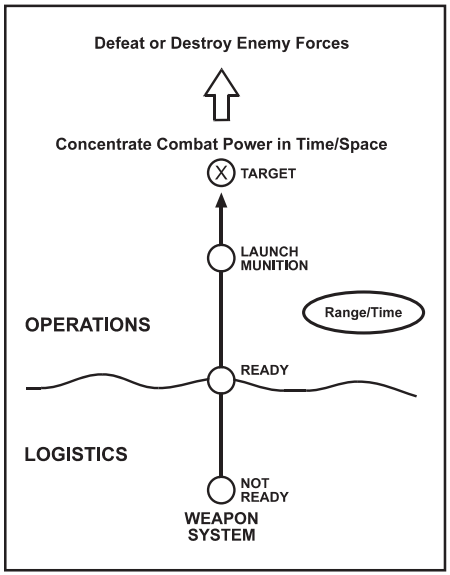

Figure 3. Mission

Logistics is made up of very simple processes, but these are arranged in a network of interdependencies that, when acting on the many different units of stuff that are needed to support each weapon, create a complex, busy, dynamic system full of variability.

Fightn' N' Stuff

But, more crucially, when we think about moving stuff, we step into a world of distance and much slower speeds. Our units of time quickly move from hours to days to weeks as we move back through echelons one to four. We stop looking at the clock and start reading the calendar. Remember, it is not just the physical transportation that takes time; it is the preparation for movement, shipping delays and simple queuing for resources and facilities that really bite.

world of operations, we are first concerned with range between the loaded weapon system and the target. This range translates into seconds, minutes or hours, depending on the weapon system. Whatever measure is used, the cycle of action—ready, aim, fire—is relatively quick. But an even more important factor is opportunity. The target is often moving and only visible or vulnerable for short periods of time. The cycle of action is not only quick; the opportunity to act is often fleeting. So readiness is crucial.

The activities that happen after—ready, aim, fire—we call recovery and regeneration. The weapon system is off-line while we check serviceability, remove and replace failed parts and reload with fuel and munitions. Time taken for recovery and regeneration is influenced by the complexity of the tasks and the availability of good stuff to replace the bad (or to fill holes in weapon racks) and skilled people and the necessary tools and equipment to do the job. There are three types of output from this process. Firstly, a loaded weapon system: this goes back into the operations world. Secondly, information: this will include failure rates, time taken to replace components and perhaps new ways of doing work faster. We will also get information on how fast we are using our stocks, how many holes need to be filled. The third output is bad stuff that has been removed and replaced; this bad stuff will be input to the logistics system. The detail of what happens to the good stuff when it returns to the world of operations is outside the scope of this article. For our purposes of understanding what influences the task of concentration, we now need to follow the bad stuff back into the logistics black hole.

In the logistics world we talk about echelons of support (Figure 4). As we move back from the interface with operations the complexity of work that can be done at an echelon increases. Typically, a first echelon task would be simply to remove and replace a black box in a system, or to rearm. At second echelon we might test functions and replace modules that can be simply plugged in or pulled out of the system. To address more complex maintenance and repair tasks, for example to do internal work on an aircraft power plant, we would expect to go back to a third echelon, where we have concentrated the skills, spares, tools and test facilities to gain economies of scale and a focus of expertise. Finally, for work such as complete rebuilds, or for small populations of very complex equipment, or processes involving exotic materials, we may move back to a fourth echelon, often to the commercial manufacturer. Where we put our echelons, and what capabilities we give them, largely determines the shortest possible time it could take to mend or replace things. How long work really takes is determined by the way we operate within this structure; in short, how effective we are as a team.

Earlier we saw that in operations we focus on opportunity and range, and we think in seconds, minutes or hours. In logistics we are first concerned with the time it takes to *mend* something, which will be at least hours and sometimes days. But, more crucially, when we think about moving stuff, we step into a world of distance and much slower speeds. Our units of time quickly move from hours to days to weeks as we move back through echelons one to four. We stop looking at the clock and

start reading the calendar. Remember, it is not just the physical transportation that takes time; it is the preparation for movement, shipping delays and simple queuing for resources and facilities that really bite. And we are not moving just one package through the system; we are moving thousands, all competing for space and attention at every stage. To understand the nature of this movement, we need to take a look at pipelines and how they interact with the stuff that moves through them.

What do we mean by a pipeline? Often the first image that comes to mind is of very long tubes of metal crossing the tundra. Pipelines getting fuel from A to B. But any means of transporting stuff can be understood as a pipeline. We can think of a convoy of trucks on a road, men on bicycles struggling along jungle tracks in Vietnam, or a production line in a factory. Whatever their shape, size and components, when we describe them in systems terms all pipelines have three basic characteristics: capacity, length and flow rate. This means: how big and how heavy can each lump of stuff be? How many lumps of stuff can we have in the pipe at any one time? How far apart are the ends of the pipe? How fast can we push the lumps of stuff down the pipe? And most important of all, how long does it take between putting a specific lump of stuff in the pipe and getting it out at the other end? Also, for many pipelines, more capability often means less flexibility. Setting up a pipeline, or changing where we put the ends, are the classic problems of the fireman. The faster the flow of water and the wider the bore of the fire-hose, the more effort it takes to move. It takes more manpower, and it takes more time. And Heaven help the fireman if he has put the fire truck in the wrong street. He cannot stretch the hose, and he will have to empty it and roll it up before he can move the truck to where it is really needed.

It gets harder; in logistics we have to deal with many pipelines, of different capabilities, in a complicated and busy network. The most obvious problem in a network is how to have some control over the many flows that merge and diverge. If we are not careful we can overload smaller pipes by putting them downstream of bigger pipes. To keep the flow going we may have to speed up flow in a smaller pipe, or restrict flow in a bigger pipe that happens to be upstream. It is like plumbing. Coupling copper and plastic pipes of different sizes is not easy. In the transportation world one of the biggest challenges is getting this transfer right.

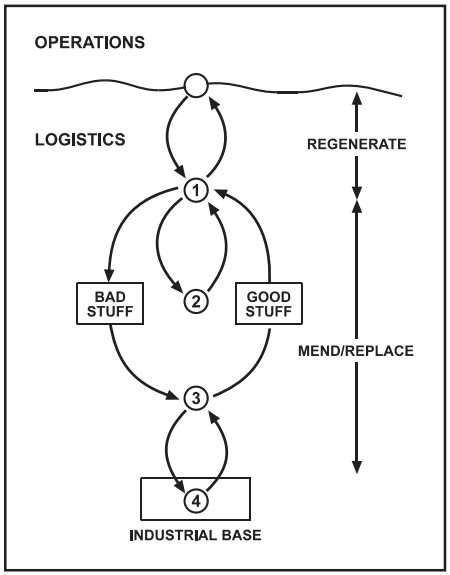

Figure 4. Interface and Echelons

Whatever their shape, size and components, when we describe them in systems terms all pipelines have three basic characteristics: capacity, length and flow rate. This means: how big and how heavy can each lump of stuff be? How many lumps of stuff can we have in the pipe at any one time? How far apart are the ends of the pipe? How fast can we push the lumps of stuff down the pipe? And most important of all, how long does it take between putting a specific lump of stuff in the pipe and getting it out at the other end?

Fightn' N' Stuff

The goal of the operations system is to concentrate combat power in time and space. To make that possible, the logistics system has to concentrate stuff in time and space, and it has to be useful stuff. What is useful is defined directly by the needs of operations.

Because of the uncertainty of demand, and the variability of the many processes connected by the logistics system network, the natural tendency of even a well designed system is for backlogs to build up and for flows to interfere with each other. Forward motion slows down and sometimes stops. In extreme cases the system can be paralysed. How can we deal with this natural tendency? To some extent the solution lies in good plumbing. We anticipate surges in flow and droughts in supply and design our system to be flexible. The most important technique is to position spares and spare capacity, at well chosen points in the system so that when there is any interruption in supply we can use the local buffer to produce what we need to fill the hole and keep forward motion going. We may think of buffers as header tanks, or reservoirs, producing steady pressure and uninterrupted flow. The goal is always to maximise throughput of the whole system. Buffers are essential but they take up space and cost money. The aim is to keep them to a minimum. Too much stuff in buffers is just as bad as too little. There is a golden rule: *just in time, not just in case*. He who breaks this rule loses his gold.

There is one more pipeline characteristic we need to consider: invisibility. Despite attempts to track progress, most pipelines are opaque. We know what went in, but we often cannot see exactly where things are now. If a package is late we will know, but not that it is going to be late. Or even how late it may be. We take a bad thing and make it worse. We hide things when we put them together on pallets in batches to get economies of scale. This is the result of an inevitable trade-off. The aggregation of stuff for transportation gives us a cost benefit and moves more stuff faster. But it also makes the task of finding, reprioritising and redirecting individual items much harder. It reduces flexibility.

As a result of our analysis we can now propose the fundamentals of any logistic system as:

- Variability of Process
- Uncertainty of Demand
- Capacity and Flexibility of the Network
- Design and Management of Buffers

The first two are conditions, two of our four key factors that relate to the general nature of the partnership we are examining. The second two are the basic characteristics of any particular logistic system we may construct. As we step up out of the world of stuff and cross the interface with the world of operations we meet the third of our key factors. It is not a condition of either world. It is the fundamental quality of the partnership between operations and logistics—synchronicity. What does this strange term mean?

The goal of the operations system is to concentrate combat power in time and space. To make that possible, the logistics system has to concentrate stuff in time and space, and it has to be useful stuff. What is useful is defined directly by the needs of operations. Simply because they share the same stuff and feed each other

with stuff and information, the processes in both systems need to be synchronised. But this is not easy to do; for two main reasons. Firstly, people working in operations and in logistics will tend to have very different time horizons. Operations is focused on range and fleeting opportunity; logistics is seeking continuous flows, often over long distances. This leads to different mind sets, a different sense of how fast things need to get done and how reactive to be. Secondly, each world has a different view of what constitutes a unit of work. The focus on stuff is different. This creates another tension between the systems that makes keeping in step hard. What is this different focus?

Logistics processes tend to batch repair work and to palletise stuff into shipments to get production and transportation economies, but this inevitably holds some things up. On the other hand, processes in direct support of operations focus on holes to be filled and therefore on the individual things that are needed to fill those holes. The urgency in the operations world to bring unserviceable weapon systems back on-line creates an imperative to get everything done immediately; from this point of view any delay is bad.

Our problem is to get and maintain synchronicity between two systems: each with a natural tendency to look at the world differently and march to different drummers. The solution lies in good system design and good planning processes and people who are comfortable with ambiguity and constant change. We have to remember the environment will always be unsteady. To succeed we need to be flexible enough to accommodate uncertainty of demand and variability of process. The truth is that logistic systems will never be easy to deal with: they are simply too complex, too dynamic, and too big. We cannot ever fully control them; we can only prepare them and sustain them. Additionally, the partnership with operations is itself complex, dynamic and dependent on many actors. The resulting condition of complexity is the last of our four key factors. It is clear that, whatever else we do, to deal with the challenge of complexity we will always have to do a lot of thinking and organising before the shooting starts, if we are to hope to win.

Our problem is to get and maintain synchronicity between two systems: each with a natural tendency to look at the world differently and march to different drummers. The solution lies in good system design and good planning processes and people who are comfortable with ambiguity and constant change. We have to remember the environment will always be unsteady.

Part Two—The Dynamics of Fightn' N' Stuff

We have looked at the fundamental nature of the partnership. Now we need to examine how it works in practice by looking at the similarities and differences in the application of land, maritime and airpower. In the case of airpower we will look a little deeper. But first, we need to think about power projection in general terms (Figure 5).

From an operations point of view, the crucial determinants of effective power are the time to strike and the rate of striking. From a logistics point of view, the crucial determinants of effective support are: time to deploy, but in terms of useful packages of capability; and time to resupply, but in terms of useful amounts of useful stuff. Getting the bombers into theatre quickly is of little value if you have not got anything there for them to drop. So how does the nature of military power determine how operations and logistics work together?

Fightn' N' Stuff

The capacity and flow-speed of supply pipelines can be increased given time and use of an air bridge can redirect the flow of force multiplier stuff very quickly, stuff like the critical spare parts that keep weapons on-line. With an air bridge direct to the operating base the pipeline can be brought right up to the weapon systems.

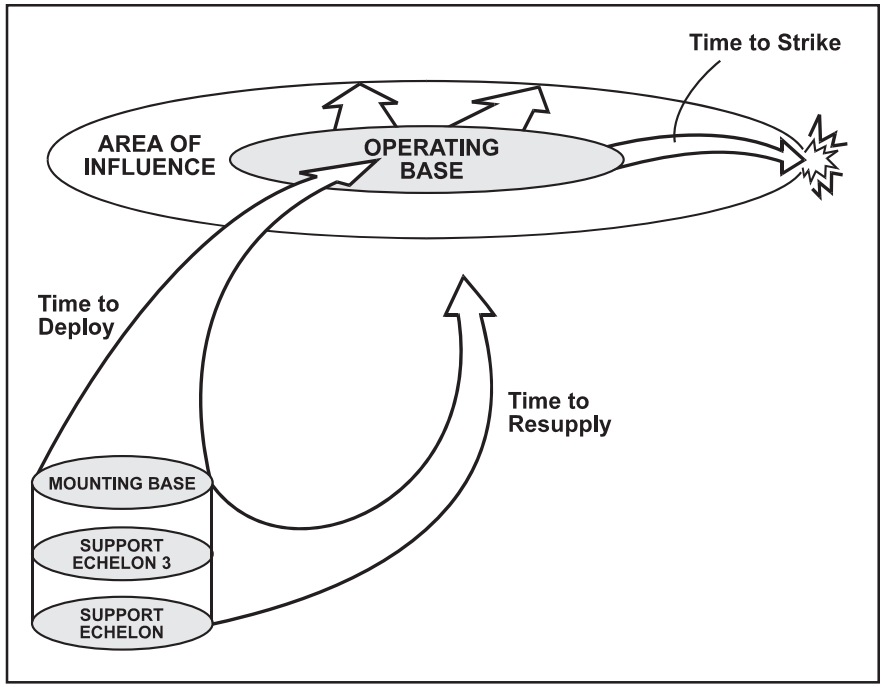

Figure 5. Power Projection

For land forces, most of the support capability is relatively close to the operating base, and everyone is close to the battlefield. The echelon structure, with stocks, is massive, slow to deploy, and relatively slow to move. We can imagine a force tethered by a large, unwieldy pipeline. It is true that in manoeuvre warfare forces may detach from the pipeline, but not far and not for long. In the Gulf we saw an operation lasting less than 100 hours resulting in an advance of perhaps 300 km. But this was at full stretch, after massive preparations and with no enemy strikes against our own logistics. The army structure moves as one; it flows in waves across the ground. Movement is punctuated by pauses to resupply and regenerate. When the forces are engaged, rate of consumption can be much faster than rate of resupply. Launch of the next offensive operation can be whenever the commander judges that enough forces are reloaded and in position to meet opportunity. Risk assessment is all. Opportunity may most often be due to enemy weakness and may be unpredictable in time and weight of effort needed. Small forces can have big effects if used suddenly, in the right place. Surprise and shock action pays off. This possibility puts a premium on mobility of logistics on the battlefield.

For naval forces, the operating base can always be moving. Because of this it has to be at the end of a long and flexible pipeline, that will of necessity be narrow and will be broken from time to time. Pipeline capacity is low and flow can be interrupted.

For this reason a naval force needs more stocks and more *mending* capability on board the operating base. Like land forces, a navy has to take its buffers into the fight. Because of this, it is more critical to get things right before deployment; catching up is hard. Maximum power is fixed at the start of the operation when the fleet leaves its home port and diminishes rapidly once engagements occur.

What does the partnership look like in the case of airpower? The list of characteristics is well known, but what do the words mean? We can propose the following interpretation. Airpower measures by the clock rather than the calendar. Airpower can go anywhere, can attack scattered targets, attack deep targets and attack simultaneously over a wide area. Airpower can be very precise; and can be responsive: in the range of capabilities, in deployment, in the tempo of operations. But we must stress the conditional nature of all these capabilities, because to do all these things we have to get our bases in place, our capability to regenerate stuff on-line and our rounds, men, and equipment in place to reload at the rate we need. And then keep it going. This, of course, is logistics.

So, for land based air, there are similar challenges as in the cases of land and maritime forces, but also some unique opportunities to get sustained, flexible, combat power by carefully synchronising operations and logistics. The operating base is static, once deployed. But new bases can be activated relatively quickly and the forces can be redeployed between bases quickly and over long distances. As a result, air forces can build up power at the base to a schedule and adjust the schedule while build up is in progress. More power can be brought to bear faster and in different places, far apart—what we may call *switchability*.

The capacity and flow-speed of supply pipelines can be increased given time and use of an air bridge can redirect the flow of force multiplier stuff very quickly, stuff like the critical spare parts that keep weapons on-line. With an air bridge direct to the operating base the pipeline can be brought right up to the weapon systems. This capability is crucial for airpower because it relies completely on technically very complex and somewhat fragile systems operating far from support echelons. Despite steady improvement in reliability and maintainability of aircraft systems, the foreseeable future operations will continue to generate significant failure rates, resulting in a great deal of difficult test and repair work. With fast, reliable pipelines vulnerable regeneration capability can be kept further back from the threat. This means the number of support forces near the battle can be reduced, and this, in turn, reduces the requirement for force protection. If fewer personnel and less equipment are sent it does not take as long to deploy a force and it does not cost as much to keep them in place. We talk about reducing the mobility footprint. Fast reliable pipelines mean the flow around the repair loop can be sped up and buffers of spares can be smaller. This reduces cost and releases funds for other purposes. For complex aircraft spares, moving them faster is usually much cheaper than buying more.

We talk about reducing the mobility footprint. Fast reliable pipelines mean the flow around the repair loop can be sped up and buffers of spares can be smaller. This reduces cost and releases funds for other purposes. For complex aircraft spares, moving them faster is usually much cheaper than buying more.

The reach of airpower means that commanders can often choose to put an operating base near or on a good transportation hub, readily maximising flow and

Fightn' N' Stuff

The goal for the partnership is to achieve concentration. To get the right stuff to the right place, at the right time, and to keep on doing it. This has to be achieved in the context of four conditions: variability, uncertainty, synchronicity and complexity.

so maximising combat power. Air forces are not constrained to line up with the enemy forces on a shared patch of ground and make the best of the infrastructure that happens to be there. Deployed air forces *en masse* are not limited by a finite magazine of weapons and the need to disengage and return to port for rearming. A word of caution: an important element of airpower flexibility comes from having a choice of weapons, but this choice can generate more uncertainty. For example, it introduces the question of what weapons to ship out in what order before the shooting starts. Here coordination between operations and logistics planning is critical. In general, air transport cannot move large quantities of heavy stuff, so we must to look far enough ahead to have time to send the bulk of weapons by sea. Nevertheless, well planned and adaptive resupply can match the consumption of stuff by air forces even under conditions of a sustained tempo of operations generated by a fast sortie cycle. If resupply is effective, air forces can reload and retask quickly and continuously. To achieve this, there must be good information and effective, integrated movement and repair processes.

We have seen that differences in the nature of the forces and their application naturally leads to differences in approach for the fundamental logistic processes of stocking, sustainment, and regeneration. These differences in process determine how forces set up their structure, how they distribute stuff around the structure and in what quantities and the rules that must be followed to best manage their activities, to achieve success. So now we understand the nature and dynamics of the partnership: what is critical to success, what really matters most in doing fightn' n'stuff.

Conclusions

The goal for the partnership is to achieve concentration. To get the right stuff to the right place, at the right time, and to keep on doing it. This has to be achieved in the context of four conditions: variability, uncertainty, synchronicity and complexity. To deal with these key factors we have to have two things, the right attitude and the right fitness: doctrine and capability. The right attitude helps us identify what must be done; fitness provides the energy and flexibility to do it. The right attitude is to think first and most about just five things.

1. The operations and logistics partnership is a target for our enemy—protect it.

We must try always to think of an enemy looking for the decisive points in the partnership. What we want to make strong, they will try to weaken. Where we want agility, they will want to paralyse us. What we can do to our enemy, we can do to ourselves by lack of attention. So all concerned with operations and logistics must protect and care for the partnership and the things it needs for success. This includes stuff and information and people. Also, we must not forget, the corollary is just as important: the operations and logistics partnership of the enemy is a target for us, we must attack it.

The layman tends to associate air superiority with destruction of enemy aircraft…it is not the only approach. A potentially vulnerable sequence of events (the aircraft chain) must take place before an aircraft fires a missile or drops a bomb …it is possible to eliminate an air force by successful attacks on any point in this chain.[4]

—Colonel John Warden III, USAF

2. Think about the physics.

Stuff is heavy and it fills space. Anything we want to do needs to take account of the weight that will have to be moved, over what distance, with what effort. Usually this all comes down to time, a delay between the idea and the act. If we think about the physics we can know the earliest time we can finish any task and we can separate the possible from the impossible. It is crucial to determine the scope of the physical logistics task early in any planning process. Planners must know how long things take and why they take that long.

3. Think about what needs to be done when—and tell everybody.

Once we have given instructions and the stuff is in the pipeline it will fill that space until it emerges at the other end. The goal is to make sure that the stuff coming out of the pipe is exactly what is needed at that point in the operation. If it is not then we have lost an opportunity—useless stuff is doubly useless. Useless in itself and wasting space and effort and time. Moving useless stuff delays operations. Even in a shooting war extra missiles are a luxury if there are already enough for the next 3 days, but aircraft are grounded for lack of engines. In setting priorities it is important to think about what might have to be done, even if it is not part of the current plan. It might be tempting to insist on maximum numbers of all alternative weapons choices being shipped to a base, but if there is no thought given to the sequence of arrival of the right mix, the enthusiastic but undisciplined outloading of weapons might put back the earliest time action can be taken. For example, changes to rules of engagement or other operational factors, such as prevailing weather conditions, may introduce limits on which weapons we can use legally or effectively. Also, priority of order of arrival will change with conditions and with the nature of the force deploying. For example, the political need to show a presence quickly may lead a commander to take the risk of using the first air transport sorties to get aircraft turn-round crews and weapons into theatre before deploying all the force protection elements.

Moving useless stuff delays operations. Even in a shooting war extra missiles are a luxury if there are already enough for the next 3 days, but aircraft are grounded for lack of engines.

4. Think about defining useful packages of stuff.

Stuff is only useful when all the pieces to complete the jigsaw are assembled. Until the last piece arrives there is nothing but something complicated with a hole in it. It is vital to know exactly what is needed to make a useful contribution to the

operational goals and to manage effort to complete unfinished jigsaws, not simply to start more. Useful stuff often has a *sell-by* date. If it arrives too late it has no value and the effort expended has been wasted. The sell-by date must be clear to everyone who is helping build the jigsaw. And it is important to work on the right jigsaw first. In any operation there is a need to relate stuff in the pipelines to Joint operational goals, not to single Service or single unit priorities. It is no good having all the tanks serviceable if the force cannot get enough aircraft armed and ready to provide air cover; or ensuring that the bomber wing gets priority at the expense of its supporting aircraft.

5. Think about what has already been started.

The length of a pipeline is measured in time not distance. There will always be a lag in the system and it is important to remember what has already been set up to happen later. Constantly changing instructions can waste a lot of energy just moving stuff around to no real purpose. Poorly conceived interventions driven by narrow understanding of local and transitory pain can generate instability and failure in the system.

So, there are five things to think about. But thinking is not enough. We have got to be smart and fit to win. It is important to conclude with some thoughts on the fitness we must seek to guarantee a robust partnership of operations and logistics.

We need systems that can cope with damage, disruption and confusion. Remember, we expect variability in performance, just by the nature of the logistic processes. We need simple rules, simple procedures and a clear view of the mission. People must be in no doubt what they should be trying to achieve. This might be compared with the notion of *mission command*. We must not build systems that are rigid and too dependent on fixed infrastructure; this mistake is usually the result of seeking local efficiencies without considering the impact on overall system effectiveness. The partnership has to be resilient. We need systems that can respond quickly and effectively to change. Remember, we expect uncertainty in demand just by the nature of the activity we are supporting. We need to be ready and able to redirect and accelerate, and we must be open to learning as we go and to exploiting new knowledge immediately. We must not become so focused on what we have planned for that we fail to recognise and respond to what is really happening. Both partner systems have to be adaptive.

We need a partnership that concentrates effort on meeting operational objectives so every action adds the maximum value to combat power. As much as we can, we must link what we do in the logistics system directly to the contribution in combat readiness. We must not work to measures of output at intermediate sections of the pipeline; we must measure all performance in terms of the outcome at the business end of the pipe. Logistics has to be focused on operational outcomes.

What we always face are trade-offs in time, investment, and operational opportunity. One of the purposes of deliberate planning, and the exercising of systems for real, is to highlight these trade-offs, to understand their

interdependencies, and to learn how to get the best result even when we do not have all the facts. A robust partnership will beat a tidy plan, every time. The focus of trade-offs at the operational level is the commander. His planning and execution must be centred all the time on the need to synchronise operations and logistics. Making trade-offs is unavoidable; variability and uncertainty see to that. But making better trade-offs, faster than the enemy, is how we win. Knowing what we are doing helps. And doing as few stupid things as possible and as many clever things as we can is important. We need knowledge on what is happening, why and how it will change things. Information on the performance of critical success measures in the process is crucial to gaining these insights. Knowing what the critical success measures are comes from good analysis and design—from asking the right questions, from thinking clearly about the system we work.

Experience teaches that most often things go wrong because of poor understanding and poorer communication, because of lack of clear focus on essentials, on what really matters. Too often we work at doing things right, not on doing the right things. We measure efficiency rather than effectiveness. Thinking about the nature of things is hard. But it is what we must do if we are to truly understand and be effective.[5]

> *Gentlemen, the officer who doesn't know his communications and supply, as well as his tactics, is totally useless.*
>
> **—Lieutenant General George S. Patton, USA**

Notes

1. Widely used misquote of, "I always make it a rule to get there first with the most men."
2. D. J. Foster, "A New Look at Wholesale Logistics," *Air Force Journal of Logistics*, Vol XIX, No 4.
3. J. P. Womack, D. T. Jones, and D. Roos, *The Machine that Changed the World*, New York, NY: Free Press, 1990 and E. M. Goldratt, *Theory of Constraints: A System Approach to Continuous Improvement*, New York, NY: Quality Press, 1990.
4. Colonel John A. Warden, III, *The Air Campaign: Planning for Combat*, Washington, DC: Brassey's, 1989.
5. C. Handy, *Understanding Organisations,* Oxford, UK: Penguin, 1993.

Lieutenant Colonel Thomas D. Eisenhauer, USAF

Leading the *Nexters* Generation

New Recruits and Leadership

The existence of a following, whether it be a ship, an air station, or a fabrication shop, compels leaders to act responsibly. A leader only occupies that position by consent—he is responsible first, last, and always to those who follow him—it is a way of life![1]

—Rear Admiral Donald R. Eaton, USN

The United States, as well as its military, has been shaped over the last 60 years by two easily identifiable generations, the Veterans and Baby Boomers. In *Generations at Work: Managing the Clash of Veterans, Boomers, Xers, and Nexters in Your Workplace*, the authors discuss the importance of understanding each new generation's core values and work ethics as developed from key seminal events that shaped their formative years.[2] This understanding forms the foundation from which leaders of today's military will recruit, train, inspire, and retain quality leaders for tomorrow's Armed Forces.

The pace of technological change continues to increase exponentially as the new millennium begins for the Armed Forces. Advances in communications, sensor to shooter interfaces, and precision weapons have blurred the lines of strategic, operational, and tactical levels of war. Just as the tools of the military profession have changed, the latest generation of military professionals has changed. Enlisted recruits and newly commissioned officers bring to the fight values, morals, and beliefs gleaned from the environment of their childhood, educational system, parental influence, and spiritual development. Veterans, Baby Boomers, and Generation Xers are tasked with leading and mentoring the newest generation—

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The Nexters are entering the workplace with 69.7 million people and a passion for technology and much greater optimism than Xers.

known as Generation Y, the Nexters, or the Digital Generation—of military professionals entering the ranks. Who are Veterans, Boomers, Xers, and Nexters?

In *Generations at Work*, the authors use a slightly different chronological description of which age groups the Veterans, Baby Boomers, and Xers belong to than other research publications. The authors interviewed a number of people in each generational category and determined that Veterans born between 1922 and 1943 had more in common with each other than the conventional grouping of those born between 1922 and 1946.[3] Baby Boomers born between 1943 and 1960 had more in common with each other than the conventional grouping of those born between 1946 and 1965. Xers are defined as those people born between 1960 and 1980, as opposed to 1965 and 1980, again due to common espoused core values. Finally, Nexters were born from 1980 to 2000. This article adopts the generation schema introduced in *Generations at Work*. Not all persons in a generation possess the characteristics described or act in the same way.[4] Presented are trends generally found in persons from the generation being discussed.

The Veteran generation is composed of 52 million people, born before and during the depression and World War II.[5] Their earliest memories and influences are strongly associated with sacrifice, duty, and honor. The Baby Boomers boast 73.2 million people.[6] Raised after World War II in a time of opportunity and progress, their childhoods are filled with fond memories of moon landings and tragic memories of assassinations and Vietnam. Generation Xers are 70.1 million strong and sometimes referred to as the *lost* or *invisible* generation.[7] Watergate and the Three Mile Island nuclear reactor incident led to disenchantment and a fierce opposition to reliance on the government. This generation became even more self-reliant with the explosion of the personal computer (PC). The Nexters are entering the workplace with 69.7 million people and a passion for technology and much greater optimism than Xers.[8] Each of these four generations is tough, intelligent, and highly capable. Successful military leaders have always tailored their leadership style to the needs of the subsequent generation and will do so again with the Nexters. Still, why should a leader be interested in understanding what makes a Nexter tick? Why should leaders want or need to earn the respect of their subordinates?

Lieutenant Hal Goetsch, US Navy, wrote an article, published in the October 1995 edition of *Proceedings* by the US Naval Institute, to address the retention problems of submariners from a submariner's perspective. "Junior officers are bored and unchallenged because they are not instilled with a sense of purpose—and that major problem will not go away with an extra [$17,000][9] a year. A sense of purpose is developed and comes from the top of an organization."[10] He is talking about leadership all the way up the chain of command. He also is talking about retention of key mid-level personnel. There is a connection between leadership and retention. Each of the services struggles with retention problems of noncommissioned officers (NCO) and junior officers. An all-volunteer military cannot afford to allow a high percentage of trained professionals to exit the ranks just when their country needs them to lead its military.

Eaton understands that challenges facing a modern military senior leader are the same as challenges we all struggle with as NCOs and officers in the profession of arms. Leaders earn the respect of those under their command. Each new recruiting cycle brings tens of thousands of new recruits into the Armed Forces. Young airmen, marines, soldiers, and sailors are volunteers who meet or exceed demanding entrance requirements. They are well-educated and often possess technological skills beyond many of their superiors. New recruits increasingly must know not just *which* job must be done but *why* it must be done and for *what* ultimate purpose. These recruits have high expectations and are confident they can make more money easily in the civilian world. They did not join the military to put food on the table or a roof over their family. They joined the military to earn money for college and for adventure, discipline, and leadership opportunities.[11] Quality of life is important, but so is a sense of purpose.[12]

Leading the latest generation entering the ranks of the Armed Forces should be of paramount concern to military and civilian leaders at all levels. A military leader has three responsibilities to the next generation. First, a leader must train personnel through education, practical experience, and mentoring. Technical training courses, professional military education (PME), and higher education are vital to developing military professionals. Experience is gained only by learning the ropes on the job. Mentoring completes the training package by providing feedback and guidance from the leader to subordinates. The second responsibility a leader must provide each and every subordinate is a sense of purpose. We have smart people. Give them an honorable vision and the support and resources to accomplish the mission. Third, retention is a key issue today. A leader must retain quality people to maintain and grow a quality force. A leader who successfully accomplishes the first two responsibilities and is successful at procuring and providing decent resources will succeed in building and retaining a high-quality military force.

This article sheds light on a combination of generational core values and leadership tools necessary for a 21st century leader. It is intended to initiate thought on the part of the reader as to what skills and tools are required to successfully lead airmen, sailors, soldiers, and marines. It does not and cannot determine the exact recipe for success, but it will provide military leaders a foundation from which they may learn to exploit and win the clash of generations in the Armed Forces.

World War II and the Draft: Veterans and Baby Boomers

Leadership is inseparable from the followers' needs and goals. If that concept is ignored, the organization becomes factionalized, progress is halted, and productivity is impossible. Leaders in any organization are essentially politicians who must deal with the realities of pressures from above and below. In the hierarchy of leadership, no one is exempt. Admirals, commodores,

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captains, department heads and ship supervisors operate in an environment of conflicting political pressures. It might be said that leadership is the art of the possible.[13]

—Rear Admiral Donald R. Eaton, USN

The nuclear age, National Aeronautics and Space Administration, civil rights, the arms race, the Cuban missile crisis, mutual assured destruction, and Vietnam convinced Baby Boomer military leaders that total war was not only unthinkable but also unacceptable.

Seminal Events

David Fromkin's *In the Time of the Americans* traces international politics of the 20th century and the coherent generation in America who defined it. They are the Veterans who came of age and began taking the reins to shape their world in the 1940s, 1950s, and 1960s. They see events from a common point of view because of their shared experiences.[14] Many tragic national and international events, as well as unprecedented accomplishments in technology, impacted their formative years. The Great Depression, World War II, the atomic bomb, the Iron Curtain, the Berlin Airlift, Korea, and Sputnik are events that shaped a critical era within the Armed Forces. Veterans guided the nation as it entered the world stage as one of two world superpowers.

While Veterans were steadfastly guiding the country through its infancy as a world superpower, Baby Boomers were born and came of age with visions of America at its best and, at times, its worst. For many Baby Boomers, the McCarthy hearings in Congress with J. Edgar Hoover's all-powerful Federal Bureau of Investigation *rooting* out the Communist element within our society are contrasted with a *My Three Sons* lifestyle and space flight.

The nuclear age, National Aeronautics and Space Administration, civil rights, the arms race, the Cuban missile crisis, mutual assured destruction, and Vietnam convinced Baby Boomer military leaders that total war was not only unthinkable but also unacceptable.[16] These military leaders guided us through a minefield of doomsday scenarios and pulled us back from the edge of the cliff. Table 1 portrays a snapshot of key events that shaped Veterans and Baby Boomers.

Core Values

Free loving Baby Boomers always have been compared against the noble Veteran generation whose sacrifices and triumphs have earned them great respect and deep admiration. Veteran core values are easily traced to the seminal events of their lives and are compared to the core values of Baby Boomers in Table 2. The core values that Veterans hold dear reflect their perception of nobility and "a dedication to service, to something greater than making a living."[17] Baby Boomers inherited a strong commitment to public service from the Veteran generation but did not feel obligated to serve in the military.[18] "Yet many of the crusades of Baby Boomers, with all their self-righteous nuttiness, resulted in solid achievements and advancement in areas such as civil rights, the environment, and women's status…."[19]

It is key to remember that not all people defined by birth year as a Veteran or Baby Boomer espouse the core values attributed to their generation, and not all

live up to them. Nor should the reader assume that a Veteran cannot be an optimist or that a Baby Boomer is always seeking personal gratification over being honorable. It does imply that there is a definite difference in the average Veteran and the average Baby Boomer. The sharp contrast in core values represents the seminal events that impacted their collective lives, amplified by an increase in global communications and television broadcasts around the country and the world in particular.

Heroes

Every generation has its heroes. Veterans lived through national and international crises that threatened their fundamental needs. President Franklin D. Roosevelt displayed incredible leadership to pull a nation through the Great Depression, initiate the New Deal, show stoic resolve following Pearl Harbor, and provide

Veterans		Baby Boomers	
1927	Lindbergh completes first transatlantic flight	1954	McCarthy HCUAA hearings began.
1929	Stock market crashes	1955	Rosa Parks refuses to sit at back of bus in Montgomery, Alabama.
1932	Franklin D. Roosevelt elected President	1957	First nuclear powerplant.
1933	New Deal	1957	Congress passes the Civil Rights Act.
1939	Hitler invades Poland	1960	Birth control pills introduced.
1940	Battle of Britain	1962	Cuban missile crisis.
1941	Pearl Harbor; US enters WW II	1962	John Glenn orbits the earth.
1944	D-day in Normandy	1963	President Kennedy assassinated.
1945	Victory in Europe and Japan	1965	United States sends ground troops to Vietnam.
1948	Berlin Airlift	1966	National Organization for Women founded.
1950	Korea	1968	Martin Luther King and Robert F. Kennedy assassinated.
		1969	First lunar landing.
		1969	Woodstock.
		1970	Kent State University shootings.

Table 1. Seminal Events for the Veteran and Baby Boomer Generations[15]

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The Baby Boomers' work ethic reflects their core values as well; however, they are more complicated. As a group, they are driven, service-oriented, and willing to go the extra mile even if that means working to exhaustion.

steadfast world leadership in World War II. Fittingly, Veterans identify with men tested on the field of battle, sports icons, national leaders, and Superman (Table 3).[21] Military legends such as General George C. Marshall; General Dwight D. Eisenhower; Admiral William F. Halsey, Jr; and General Douglas MacArthur provided Veterans with noble goals, a clear path, and unwavering efforts toward eradicating fascism and rebuilding Germany and Japan.

The world became even smaller through exponential advances in transcontinental aviation, trade, and communications. The United Nations grew out of the ashes of the League of Nations as the international governing body dedicated to providing a worldwide forum for international law, trade, and security. Liberalism enjoyed a Renaissance of unprecedented proportions as numerous enlightened events took place. Colonies of former empires sought and achieved independence. True advances in civil rights of all peoples were made and codified in law. The women's liberation movement broke many barriers in many cultures. And incredible technological developments sent men to the moon and returned them safely to the earth. Baby Boomers who joined the military did so with great shoes to fill and high expectations. Selfless and visionary, they got their taste of battle in and over the jungles of Vietnam.[22] Lessons learned from this painful chapter of American history were indelibly imprinted on their souls, as well as a disillusioned population at home.

Baby Boomers gravitate toward heroes whose accomplishments transcend international politics and national security.[24] Jacqueline Kennedy; Dr Martin Luther King, Jr; and Gandhi are included as heroes by the average Baby Boomer.[25] Diversity, idealism, and an optimistic vision about the future of the United States and the world permeate this generation. They notably ignore President Lyndon B. Johnson, General William C. Westmoreland, and Jane Fonda.

Work Ethic

Seminal events, core values, and heroes of the Veterans and Baby Boomers provide us a foundation for comparison of these two key generations. But how do they function and react in the workplace, under pressure, and in combat?

Veterans entered the workforce in the 1940s, 1950s, and 1960s. The average company divided the labor between executives and employees and had a clear organizational hierarchy.[26] Nearly every company maintained military-style relationships whereby most people were formally referred to as Mr or Mrs Doe. Regardless of their social, economic, or cultural roots, this generation has a very consistent work ethic. The average Veteran is very stable, detailed, thorough, loyal, and hard-working.[27] The Veteran's work ethic was mostly seen as strength; however, it sometimes was seen as a liability. For instance, ambiguity and change are difficult for Veterans to cope with. They were reluctant to go against the grain, were uncomfortable with conflict, and did not speak their minds when they disagreed.[28]

The Baby Boomers' work ethic reflects their core values as well; however, they are more complicated. As a group, they are driven, service-oriented, and willing to

Veterans	Baby Boomers
Dedication/Sacrifice	Optimism
Law and Order	Team Orientation
Delayed Reward	Personal Gratification
Hard Work	Health and Wellness
Respect for Authority	Personal Growth
Patience	Youth
Conformity	Work
Duty before Pleasure	Involvement
Adherence to Rules	
Honor	

Table 2. Core Values of Veterans and Baby Boomers[20]

Veterans	Baby Boomers
Superman	Gandhi
Franklin D. Roosevelt	Martin Luther King, Jr
MacArthur, Patton, Montgomery, Halsey, and Eisenhower	John and Jacqueline Kennedy
Winston Churchill	John Glenn
Audie Murphy	
Babe Ruth	
Joe Foss	
Joe DiMaggio	

Table 3. Heroes of Veterans and Baby Boomers[23]

go the extra mile even if that means working to exhaustion. They are good at relationships, want to please, and are good teamplayers. On the downside, they are uncomfortable with conflict, reluctant to go against peers, govern by consensus to the point of gridlock, and are not naturally *budget minded*. Baby Boomers do not receive feedback well, harshly judge those who see things differently, and are self-centered.[29] Baby Boomers are strikingly different from Veterans when it comes to the workplace, but those differences can be traced directly to the context of their formative years.

All-Volunteer Military: Xers and Nexters

Because people are better informed, the leader of today is more likely to deal with subordinates who resent being treated as subordinates, who may be critical of any organizational system, who expect to be consulted and to influence their

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own destinies, and who often stand on the brink of alienation from the very institution that depends on their loyalty and commitment.[30]

—Rear Admiral Donald R. Eaton, USN

Veterans lived through national and international crises that threatened their fundamental needs.

Seminal Events

Generation Xers only now are beginning to exert their leadership influence within the military ranks and society. They have been referred to as the *lost* or *invisible* generation while growing up in the shadows of the Baby Boomers. Xers quietly have observed events such as Vietnam, Watergate, and the Jonestown suicides (Table 4). These events are very emotionally significant to 20th century Baby Boomer liberals. They evoke stoic acceptance by Veteran realists. Xers are a generation that "no one ever really noticed, that didn't exactly register, until recently. That quasi-invisibility, born of living in the long shadow of 'The Boom,' was but the lull before the storm of identity building."[31] They witnessed the women's liberation movement, modern terrorism, and the advent of computers. Xers lived through the post-Vietnam 1970s and the Reagan administration's effort to rebuild our *hollow* forces, both in terms of equipment and spirit, into the powerhouse displayed later in Desert Storm.[32] The 1980s brought direct terrorist actions against the Marines, the Challenger disaster, the stock market minicrash, and the destruction of the Berlin Wall. World peace was declared by the Baby Boomers following the Gulf War and the dissolution of the Union of Soviet Socialist Republics in 1991. Close the history books. The Baby Boomers saved the planet. Xers can remain anonymous.

Xers had a different take on the status of world peace, and only in the 1990s has that view gradually been exerted. Generation X viewed the events of the 1970s, 1980s, and 1990s as an increasingly alarming wake-up call to America. We seemed to be a superpower that could be intimidated by any country that chose to stand up to us unconventionally.[34] North Vietnam, Iran, Cuba, North Korea, Central and Latin America, Serbia, and any one of a dozen Middle Eastern and North African countries routinely challenged our politics, economic policies, and morally superior attitude. Xers could remain anonymous no longer.

All the while, the Nexters have been growing up in families from both the Baby Boomer and X generations. More so than at any other time in history, older parents, single parents, nontraditional parents, and *daycare* parents are raising a generation bred on MTV, digital technology, and diversity.[35] Sex scandals, school shootings, homegrown and international terrorism, and the vast Internet are leading influences in their lives. Globalism permeates this generation.

Core Values

Like prior generations, the core values of Xers and Nexters can be traced to seminal events, as well as parental guidance, cultural, and spiritual influences. Being the *invisible* generation, Xers learned to be self-reliant. This one core value permeates every facet of their lives, from relationships to the workplace. Xers are survivors and uninterested in extraneous material. Bullet background papers are the perfect

	Xers		Nexters
1970	Women's Liberation protests.		Nexters are marked thus far more by trends than events.
1972	Palestinian terrorists kill 17 Israelis at Munich Olympics.		
1973	Watergate scandal.	Trends	Child focus.
1973	Energy crisis.		Technology.
1976	Tandy and Apple market PCs.		Busy, overplanned lives.
1978	Jonestown mass suicide of 900 (Jim Jones cult leader).		Stress.
1979	Three Mile Island nuclear reactor nears meltdown.		Violence.
1979	Iran takes 66 Americans hostage.		Clinton/Lewinsky.
1979	Desert One hostage rescue attempt ends in military disaster.	Events	
1980	John Lennon assassinated.		
1983	283 Marines killed by terrorists in Beirut, Lebanon.	1991	Gulf War.
1986	Space Shuttle Challenger disaster.	1991	Cold War ended and peace broke out over the world.
1987	Stock market plummets.	1993	Waco, Texas.
1988	Terrorists blow up Flight 103 over Lockerbie, Scotland.	1995	Oklahoma City bombing.
1989	Exxon Valdez oil tanker spill.	1999	Columbine school shootings.
1989	Berlin Wall torn down.	2001	9/11 terrorists attack by Usama Bin Laden's Al-Quaeda network.
1991	Gulf War.		Ongoing war on terrorism.
1991	Soviet Union dissolves.		
1992	Rodney King beating videotaped; followed by Los Angeles riots.		

Table 4. Seminal Events for the Xer and Nexter Generations[33]

The Baby Boomers' work ethic reflects their core values as well; however, they are more complicated.

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Generation Xers only now are beginning to exert their leadership influence within the military ranks and society.

written communication for them. Each of the other core values in Table 5 relates to being open to differing ideas and new technology. For instance, *think globally* implies an open mind to other cultures, religions, beliefs, and politics. *Technoliteracy* implies an understanding and appreciation for the digital technology explosion but not a consuming desire to master it, just exploit it. Fun is the core value that may keep this generation off Prozac and Viagra. Fun implies appropriate management of their home, work, and personal life that will keep this generation well grounded and balanced.[36]

Nexters seem to have core values of evolved Baby Boomers. Optimism, diversity, street smarts, and civic duty are extremely important to them.[38] The truly interesting thing about Nexters and younger Xers is that they know more about the Internet than their bosses and, thus, are entering the workplace in a commanding position when it comes to digital technology.[39] Parents are learning about technology from their kids. Another interesting turnaround is a commitment by many Xer and older Baby Boomer parents to their families. Many parents were disillusioned during their upbringing in two-career parent households. In *Generations*, Howe and Strauss state, "Not since the early 1900s have older generations moved so quickly to assert greater adult dominion over the world of childhood—and to implant civic virtue in a new crop of youngsters."[40]

Heroes

True to their reputation as a generation, Xers do not profess to have any heroes.[41] In a sense, maybe they are their own heroes since self-reliance dominates their core values. It can be argued that it is still too soon for such survivalists to settle upon a collective group of heroes. They are just exerting their influence in society and the military. In 20 to 30 years, they will have endured enough to be able to identify those whom they admire and respect. It takes time.

Nexters do not have or need time to decide whom they admire. A brief look at this group, and it is obvious that strength of character, not just individual accomplishment, is reflected in this diverse group of heroes. If the core values and heroes noted in Tables 5 and 6 are any indication, Nexters have a bright future.

Work Ethic

Xers have a very simple work ethic. Give them meaningful projects in a nonmicromanaged work environment and get out of the way.[43] Xers are self-developing, quick studies and able to handle multiple tasks in a chaotic environment.[44] They react negatively to regulations and requirements that restrict them for no apparent reason. Mandatory means and methods for accomplishing the job only will cause them to question the competence of the leadership in a company or at the highest ranks in the military.

Nexters are surprisingly realistic about their expectations in the workforce.[45] They are optimistic about the future and possess many of the positive traits of Veterans, Baby Boomers, and Xers. "They combine the teamwork ethic of the Boomers with the can-do attitude of the Veterans and the technological savvy of the Xers."[46]

Xers	Nexters
Diversity	Optimism
Thinking Globally	Civic Duty
Balance	Confidence
Technoliteracy	Achievement
Fun	Sociability
Informality	Morality
Self-reliance	Street Smarts
Pragmatism	Diversity

Table 5. Core Values of Xers and Nexters

Xers	Nexters
None	Michael Jordan
	Princess Diana
	Mark McGuire and Sammy Sosa
	Mother Teresa
	Bill Gates
	Kerri Strugg
	Mia Hamm
	Tiger Woods
	Christopher Reeves

Table 6. Heroes of the Xer and Nexter Generations[42]

Nexters are very resilient and actually believe hard work and goal setting are vital to achieving what they want in life.[47]

Challenges to Leading the Nexters

> *Sociological conditions today have fostered individuals who are jealous of their rights and demand a fair share of rewards and recognition. They demand to be treated as individuals, are skeptical of authority, and very aware that they are more qualified than ever.*[48]
>
> **—Rear Admiral Donald R. Eaton, USN**

Corporate America, as well as the military, is well aware that the population of the United States is quite unique. "America is often called a melting pot. …[Some say] it is a salad. It is really more of a stew."[49] Generations of immigrants from all over the world have sought a new life with increased opportunities here in America. Values and beliefs from literally hundreds of cultures have been—and continue to be—transplanted into communities around this nation. The Armed Forces have benefited from the diverse roots and aptitude found in its recruits. The educational

Generation X viewed the events of the 1970s, 1980s, and 1990s as an increasingly alarming wake-up call to America.The truly interesting thing about Nexters and younger Xers is that they know more about the Internet than their bosses and, thus, are entering the workplace in a commanding position when it comes to digital technology. Nexters are surprisingly realistic about their expectations in the workforce.

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level of the average enlisted and officer service member has dramatically increased.[50] Professional military education, an all-volunteer force, and decent pay and benefits have combined to make the Armed Forces arguably the best military in the world. Yet, the challenges of leading each new generation grow more complex. Cultural differences that add flavor to the stew inevitably collide with generational differences leading to conflicts and barriers in society, as well as the military. These conflicts and barriers are not insurmountable, but they do exist and must be addressed by leaders.

Cultural (Generational) Differences

There are differences in the four generations that resemble cultural differences. In the first chapter of *The Origins of Cultural Differences and Their Impact on Management*, Jack Scarborough succinctly describes culture. Culture is "the set of values, attitudes, and beliefs shared by…a group, which sets the standards of behavior required for continued acceptance and successful participation in that group."[51] We commonly think of culture in terms of nations or ethnic groups, but any cohesive group has a culture.[52] Groups as diverse as the Navy Seals, IBM, NRA, NOW, Trekkies, and computer geeks all have a culture that is passed on to newcomers from their predecessors. Veterans, Baby Boomers, Xers, and Nexters have a culture all their own. Given that any cohesive group has a culture, how can we determine key elements of the Nexters or other groups?

Edgar H. Schein analyzes culture at three levels: artifacts, espoused values, and basic underlying assumptions.[53] Artifacts are "phenomena that one sees, hears, and feels when one encounters a new group with an unfamiliar culture."[54] Nexters and some Xers are entering the military with noserings, tattoos, and other visible artifacts that are easy to observe but difficult to figure out.[55] Espoused values are shared values or beliefs that ultimately become shared assumptions within the group.[56] The goals or philosophy of Nexters, thus, may be quite different from Xers, Baby Boomers, or Veterans, yet not outwardly identifiable. Finally, the deepest level of culture is composed of basic underlying assumptions that are simply realities to that culture.[57] Basic underlying assumptions are not even periodically reviewed or pondered. Determining these within the Nexter generation is difficult at best but is the ultimate source of values and actions that drive Nexters and other cultures.[58]

The core values of Veterans, Baby Boomers, Xers, and Nexters identified in Tables 2 and 5 are values that social anthropologists generally use to identify a group or culture.[59] There is no requirement that all members of a group exemplify the core values of that group. They are values you can typically expect to find in members of a particular group or, in our case, generation. Core values motivate our actions, are reinforced from shared experiences, and are reflected in a culture's religion, political power, economics, physical trappings or surroundings, leaders, heroes, legends, and myths.[60] Military leaders must recognize that the core values of Nexters, or any generation, are espoused values or even basic underlying assumptions within the Nexter culture. Influencing, let alone changing, core values is not practical.

Recognizing and understanding Nexter core values is the answer. As noted in Table 5, Nexters espouse eight powerful core values that shrewd military leaders can capitalize on.

To further grasp the core values of Nexters, three dimensions that greatly affect Nexters, as well as the culture of the generations that lead them, are discussed. Having a purpose in life is one key core of value dimension.[61] Baby Boomers work 60 to 120 hour workweeks. Their purpose in life is to work. They *live to work*.[62] Conversely, Xers see no purpose with earned income sitting in the bank or tied up in investments while they have no time to enjoy the fruits of their labor. Xers *work to live* and seek jobs with reduced pay and hours but greater benefits and leave options.[63] In the military environment, this equates to cutting through to the heart of issues and disregarding the trappings. Tell them what they need to know and the objectives, give them the tools and resources, and get out of the way. Nexters are optimistic about the future and realistic about the present. "They combine the teamwork ethic of the Boomers with the can-do attitude of the Veterans and the technological savvy of the Xers."[64] One study quoted in *Generations at Work*, titled Gen2001, showed that 85 percent of the Nexters surveyed had established goals for the next 5 years.[65] This indicates strong espoused values within the Nexter culture. Military leaders must provide this generation with an honorable sense of purpose. A second key core value dimension is the societal role. Some people prefer to work alone, maximize their individual wealth, and are highly competitive. Others work best when part of a team, look for win-win solutions, and contribute to group success. Knowing what motivates an individual provides the commander flexibility in determining how best to use subordinates. One key question military leaders should ask Nexters, as well as themselves, is do they feel more loyalty to their unit or to their personal interests?[66] The core values Xers espouse suggest they are more loyal to their personal interests. Nexter core values indicate they are more loyal to unit interests. A third key core value dimension has received much scrutiny throughout the 1990s. Are ethics absolute or situational? "Is the same conduct always right or wrong? Are there absolute moral principles by which all must abide, or must standards depend on the circumstances? More specifically, can my obligations to a particular person (or client) supersede my general or universal duties to society at large?"[67] These questions were tested to the limit in front of the entire nation during the 1990s and impacted at least three Presidential elections. Nowhere is this dimension more important than the deadly serious profession of arms. Nexters expect their commanders to be ethical and moral pillars or, at least, keep within certain well-established boundaries. Military leaders must review and reflect on their core values periodically to ensure they are providing the right vector to Nexters.

Now that the core values of Nexters are understood, it is important to note that the core values of military leaders will not always be the same as those of the followers. Ethnocentrism describes what happens when one culture tends to see itself as "normal and superior and the other aberrational and inferior."[68] Twenty-first century leaders cannot afford to be ethnocentric. Ethnocentrism is a common fault

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Ethnocentrism is a common fault of societies and cultures.

of societies and cultures. Jack Scarborough quotes a study conducted by Geert Hofstede, where, with the 60 nations included in his study, the United States was the most individualistic.[69] Another researcher, Fons Trompenaars, found Americans very high "in universalist ethics, individualism, specificity in our separation of work from social discourse, achievement orientation, and in a sense of control over nature and our own destiny."[70] Said another way, Americans are extremely ethnocentristic—and for good reason. Ethnocentrism falls in the realm of espoused values and maybe even basic underlying assumptions. Baby Boomers, Xers, and Nexters have never known a world where the United States has not been a superpower. American exceptionalism is arguably a basic underlying assumption for most corporate and military leaders. Military leaders should guard against this assumption. They must also avoid being generationally ethnocentric when dealing with Nexters if they hope to gain their respect. Respect is something the follower bestows on the leader who earns it.

Conflicts and Barriers Between Generations

In addition to fundamental cultural dimensions, there are basic conflicts and barriers between generations within any given society. There are four areas of conflict that all generations must address to bridge the cultural and generational gap between Nexters and current military leadership. These four conflict areas were derived from systematic review of annotated texts in the bibliography and the personal experience of the author.

The first area is technical competency of the *new* generation versus experience of the *old*. Each generation is faced with the task of training its replacements in society and, in our case, the military. Oftentimes, we are not ready for the speed at which the newer generation wishes to take the reigns. Nexters already are more competent in digital technology than Xers, let alone Baby Boomers or Veterans.[71] Why should we not allow them to just cut in at the front of the line and take over now? They are not experienced and have not earned their stripes. These are common justifications for the older generation to delay transition to the newer generation. Military leaders must continually educate, train, and provide operational experience to Nexters.

Second and third, the ability to communicate and people skills are vital to breaking down barriers and resolving conflicts. In the military ranks, we have a legacy of being brutally direct in what we say, the content of communication. We must be as adept with our people skills in how we say it—the context of communication.[72] Xers appreciate the directness of the content but are turned off by poor or inappropriate delivery. Nexters are very sociable and adept at transmitting as well as receiving communications in a variety of technical methods. Video teleconferencing, digital recordings, and e-mail are all excellent to facilitate getting a commander's message out. But two methods of communication must not be lost. The telephone or 15 minutes of one-on-one personal discussion lets subordinates, superiors, and peers know they are important. It is easy to provide feedback to a computer screen, but one-on-one is more effective. Nexters are more

sensitive than Xers. People skills, which provide the context of communication, thus, are even more important for this latest generation. The greatest barrier to leadership is the lack of desire for the follower to receive information the leader is transmitting. Conversely, military leaders frequently must turn off their transmitters and concentrate on receiving communication from Nexters. How military leaders communicate with Nexters using their people skills is of vital importance.

Finally, the greatest bridge across generations and cultures is trust. Trust is difficult to gain and easy to lose. It must be earned through leadership by example, consistency, experience, competence, work ethic, and living up to noble core values. Nexters, just like all generations before, will look to those leaders who consistently meet their level of expectation. Goetsch's article *Keeping the Generation X Junior Officer* is a classic example of shattered trust in military leadership.

> *Junior officers are chosen less for their scholarship, cognitive ability, and leadership potential and more for their uncommonly high threshold of pain and their distinct ability to follow directions. That realization—not quality-of-life issues or recreant attitudes prior to entering the submarine force—is at the heart of the retention problem.*[73]
>
> **—Lieutenant Hal Goetsch, former US Navy officer**

The military must maintain trust within itself, and so must military leaders maintain trust between themselves and the Nexter generation. "Retention, like quality, is free if top leadership fosters the right environment and cultivates its next generation."[74] Sentiments such as those from Xer junior officers like Goetsch beg the question, is there a crisis between military leadership and the latest generation?

The military must maintain trust within itself, and so must military leaders maintain trust between themselves and the Nexter generation.

Crisis? Or Opportunity!

> *It follows then that authority is entitled only to the respect it earns and no more. With the stage thus set, leadership is a matter of eliciting cooperation, rather than commanding obedience. It is a matter of being mindful of the needs of people in the context of a common mission.*[75]
>
> **—Rear Admiral Donald R. Eaton, USN**

So, is there a crisis with the entrance of the Nexters onto the work stage? It is beneficial to note the military is not alone in facing this issue. The commercial world also must struggle successfully with this leadership challenge, which is reflected in the following quote from *Generations at Work: Managing the Clash of Veterans, Boomers, Xers, and Nexters in Your Workplace.*

> *Today's American workforce is unique and singular. Never before has there been a workforce and workplace so diverse in so many ways. The mix of race, gender, ethnicity, and generation in today's workplace is stunning…. There is a growing realization that the gulf of misunderstanding and resentment*

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between older, not so old, and younger employees in the workplace is growing and problematic. It is a rift that will not heal itself or just go away, as so many organizations—those even aware of it—fervently hope. It is a problem based on economic, demographics, and worldviews that must be confronted to be solved.[76]

—Ron Zemke, Claire Raines, and Bob Filipczak

As Nexters come on the work scene and join the ranks of the Armed Forces, an age-old scenario will play out over the next 2 decades.

Crisis

As Nexters come on the work scene and join the ranks of the Armed Forces, an age-old scenario will play out over the next 2 decades. The military will lose its edge, rust, and fade away because of a loss of tradition, disrespect for authority, and no vision by the latest generation. This prediction is based on the ethnocentric view of the previous generation, and it has yet to happen in American society. But it could, could it not?

Along with the guilt was nagging anxiety that the new generation might not be up to the task. "Many observers considered us a lost generation and feared we might collapse if summoned to some crucial battlefield," recalled James Michener. Many veterans of World War I looked at the new cohort of American soldiers and feared they had been softened by the antiwar ideas of their overindulgent mothers during the 1930s. "Our men who had to do the fighting didn't want to fight," concluded one veteran war correspondent. "They had been told in the all-important first ten years and in their teens that it was not necessary to fight. Our men just wanted to go home." The campaigns of 1942 and 1943 quickly erased these doubts. Indeed, by the end of the war, the GI had become a universal American symbol of courage and prowess.[77]

—Ronald H. Spector

Nexters bring to the table their own vision of the world in which they want to live. Inevitably, this vision will be different from that envisioned by Xers and definitely not the same as Baby Boomers. Service traditions, military traditions, customs and courtesies, and patriotism all come into question when a definable new generation takes the mantle. Spencer Johnson uses cheese as analogies for what we *have* and want to *keep*.[78] Boomers and Xers are in charge—they have cheese—and it makes them happy.[79] The cheese is very important to them, and they want to hold onto it.[80] In other words, their tendency is to hold onto power, not delegate authority. Their dilemma is that if they do not change they will quickly become extinct.[81] The power they are so desperately trying to hold onto will transfer anyway. Commanders who fear change—who want to hold onto their cheese for dear life—fall into the category of managers versus leaders. As Table 7 shows, what the followers of any new generation need are leaders more than managers. Military officers must train their replacements constantly for very practical reasons. They will either be

promoted and pass on responsibility to a subordinate at a change of command, or they will be replaced and the mantle of responsibility transfers anyway to a subordinate at an assumption of command. Of course, if they do change, they will become extinct anyway, but the military, as an institution will be much better off for their wisdom and mentorship.

> *Leaders are people who do the right thing. Managers are people who do things right.*[83]
>
> **—Warren G. Bennis**

Respect, trust, and confidence in the commander are vital to any unit in today's Armed Forces. New generations entering the ranks strike fear in some commanders who are convinced that respect for authority will become a thing of the past. Respect, trust, and confidence in authority are earned. In AU-2, *Guidelines for Command,* ten points of advice to commanders, as well as several additional tips, boil down to earning the respect of subordinates through consistent, concerted efforts.[84] During a crisis, it becomes quite evident who is a *leader* and who is a *manager.* Consistent, concerted leadership is critical in the profession of arms when chaos and crisis in the battlespace—or the Pentagon—rule.

Respect, trust, and confidence in the commander are vital to any unit in today's Armed Forces.

Opportunity

Opportunity is the side of the coin opposite crisis or chaos. Military managers avoid crisis and dynamic environments (Table 7), but leaders thrive and grow on ambiguity and conflict and even *failure*.[85] In the book *Rules & Tools for Leaders*, the author, Major General Perry M. Smith, describes a somber leadership experience where he was rewarded with a promotion:

> *About a month after my promotion was announced, I asked the commander of all US Air Forces in Europe how I could possibly have been selected for promotion. The answer I got was fascinating; he replied, "Because you handled failure well." When I told him that I didn't understand what he meant, he told*

Managers	Leaders
Problem solvers	Analysts of purposes and causes
Statistics driven	Values driven
Seek conflict avoidance	Not only accept but invite conflict
Thrive on predictability	Thrive on ambiguity
Ensure organization objectives are achieved even if they disagree with them	Ensure their objectives and those of the organization become one and the same

Table 7. Trait Comparison Chart of Managers and Leaders[82]

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me that each wing commander was failing in one way or another. One had a major drug problem on his base, another had flunked a major NATO [North Atlantic Treaty Organization] inspection, a third commander had a significant racial problem on his base, and yet another had a terrible ground-safety record. He then explained that he learns more of the character of leaders while they are dealing with failure than when they are succeeding.[86]

—Major General Perry M. Smith, USAF, Retired

Military leaders need to know how to develop the full potential of Nexters and not fear their ascension in the ranks. The author feels strongly that, through research and experience, three key elements of leadership development in the military are critical to Xers and Baby Boomers as they attempt to lead Nexters. First, military leaders must provide a roadmap for the Nexters. Table 8 depicts a sample leadership roadmap developed by the author.

This roadmap allows Nexters to chart their own course, yet be guided by experienced military leaders. Second, acquiring and providing proper resources, to include money and manpower, is critical. The military does a fantastic job of accomplishing more with less. However, cheap exercises using computer-simulated scenarios do not make up for exercises with real weapon systems and qualified personnel. Finally, mentoring in the proper sense of the word is vital to military *leadership*. Mentoring military leaders seek out their troops on their home turf (shop, flight line, or office), find out what they are doing, spend time listening, and provide guidance when needed.[88] These three leadership elements augment a leader's ability to seek out and cope with change. Managers are concerned with coping with complexity and finding solutions to complicated problems. A change in the environment or people creates more complexity and threatens a manager's very existence.[89] Military *managers* worry exclusively about the product and neglect the leadership process.

…a peacetime army can usually survive with good administration and management up and down the hierarchy, coupled with good leadership concentrated at the very top. A wartime army, however, needs competent leadership at all levels. No one yet has figured out how to manage people effectively into battle; they must be led.[90]

—John P. Kotter

As discussed previously, Nexters already are more knowledgeable in nearly all aspects of the digital world than the vast majority of Xers and certainly the Boomers and Veterans. They think digitally with a depth of knowledge that will bring forth technological innovations of incredible dimensions if only we just get out of the way. Nexters bring a lot of weapons to the fight. The test of our leadership will be to take Nexter digital knowledge and experience and develop them into future

1.	Assign all officers to operational units for first duty assignment to gain practical experience—including engineering, acquisition, and other Air Force Materiel Command duty specialties.
2.	Provide mandatory technical training in the individual's specialty (depth) as well as cross training in communications, leadership, logistics, and the art of war (breadth).
3.	Provide mandatory professional military education to enhance professional development and refocus the warriors at critical points in their career to ensure growth and maturation.
4.	Assign all officers to staff positions no more than 3 consecutive years before returning to operational units. Assignments to nonoperational jobs should be career broadening but temporary for military personnel.
5.	Ensure this roadmap for leadership development has a time line to ensure the right experience and training are accomplished at the right time during a career.

Table 8. Roadmap—for All NCOs and Officers—to Develop Senior Leaders[87]

leaders. Their out-of-the-box thinking—inherent in any new generation—is strength and must be recognized as such. Future wars will expose front-line marines, soldiers, sailors, and airmen to a wide range of threats. These threats include sticks and stones, as in the case of the Intifada versus the Israeli Defense Force, to precision weapons and Internet cyber-attack. The ancient and holy trinity of warfare—move, communicate, shoot—will be taken to whole new dimensions, requiring highly educated, trained, and experienced warriors.[91] As witnessed during Enduring Freedom, individual front-line soldiers are communicating and executing precision strategic strikes while in real-time direct contact with senior leadership half a world away. The sensor to shooter interface is fusing in front of our very eyes, no longer just a vision but a reality. Marvin Leibstone wrote of this very subject in 1994: "the advanced combat soldier will engage cooperatively in ways turning many forward echelon ground and air platforms into his parallel partners."[92] Accomplishing this metamorphosis takes enlightened warriors with an extensive breadth of knowledge and experience. Their individual actions and real-time decisions will undoubtedly have immediate tactical, operational, and strategic effects.

Leading the Nexters will be different from previous generations in the specific areas of what motivates them or turns them off. But the fundamental leadership tools that worked for previous generations are still recipes for success today and tomorrow. Some salient *rules and tools* are addressed in Table 9.

There is a vast opportunity in the ranks of the Nexters as they enter the Armed Forces and make their presence known in the battlespace. General Charles C. Krulak, former Commandant of the Marine Corps, made a point of studying Xers and early Nexters to understand his target audience and capitalize on this knowledge during the crucial training cycles at Quantico and other installations.[94] Krulak is convinced that communication, "the passing of experience from one generation to another is the responsibility of every officer in our Corps."[95] Nexters "want to be

part of something that is recognized as a powerful entity."[96] Maybe they want a sense of purpose.

Commanding Nexters and Beyond

Fail to honor people, and they will fail to honor you; but of a good leader who talks little, when his work is done, his aim fulfilled, they will say: We did this ourselves.[97]

—Lao-tzu, Chinese poet and philosopher

Cheap exercises using computer-simulated scenarios do not make up for exercises with real weapon systems and qualified personnel.

Summary

This article attempted to provide an answer to the question, how can experienced leaders of today's military lead the newest generation—known as Generation Y, the Nexters, or the Digital Generation—of military professionals entering the ranks.

Table 10 summarizes the four primary generations of the last 60 years. Each generation was shaped by seminal events leading to their core values, heroes, and work ethic. Veterans were shown to be noble, Baby Boomers ideal, Xers independent, and Nexters a blend of their best qualities. Cultural differences add diversity and flavor to each new generation. The generational diversity seemingly creates conflicts and erects barriers between generations. Managers who want Nexters to conform to their expectations fear these challenges. These challenges that managers see as crises with the Nexters, military leaders see as opportunities. Despite the reservations and concerns of Baby Boomers and Xers, Nexters are entering the workplace and military ranks probably with the best set of personal tools that any other generation has possessed.[99] Baby Boomers and Xers have a rich resource with which to lead the Armed Forces through any national security crisis. Despite this optimism for the Nexters, Baby Boomers and Xers must deal with an issue that cuts across generations. Anyone in uniform has repeatedly identified it as the number one issue impacting the unit, and it became glaringly obvious during the research for this article that it will continue to be the number one issue facing the Armed Forces for the foreseeable future—retention.

Conclusion

Retention of quality leaders has plagued the Armed Forces for decades but has become more acute as our all-volunteer military relies more and more on our people versus our technology. What is quite evident from the research is that a sense of purpose, real responsibility, and a chance to lead are uppermost in the minds of junior officers and NCOs in all branches of the military.[100] Articles in the *Air Force Times*, *Navy Times*, *Marine Corps Gazette*, and *Army Times* all provide supporting comments from the Xer and Nexter enlisted and officer ranks. *Joint Forces Quarterly* and the *US Naval Institute Proceedings* articles echo the unofficial service newspapers. At the very heart of these articles lies the issue of retention. It is vital to

1.	Establish standards early.
2.	Take care of your people.
3.	Look at yourself and be introspective.
4.	When leading in a crisis, be cool and flexible.
5.	Deal with cultural complexities and national antagonisms overseas.
6.	Do what needs to be done including firing a subordinate when necessary.
7.	Remember, succeeding may be measured more by how you handle failure than in how you handle triumph.

Table 9. Seven Basic Tips for Commanders[93]

	Veterans	Boomers	Xers	Nexters
	1922-1943	1943-1960	1960-1980	1980-2000
Outlook	Practical	Optimistic	Skeptical	Hopeful
Work Ethic	Dedicated	Driven	Balanced	Determined
View of Authority	Respectful	Love/Hate	Unim-pressed	Polite
Leadership by	Hierarchy	Consensus	Compe-tence	Pulling
Relationships	Personal sacrifice	Personal gratification	Reluctant to commit	Inclusive
Turnoffs	Vulgarity	Political incorrect-ness	Cliche, Hype	Promiscuity

Table 10. Comparison Chart of How Each Generation Views the World[98]

The test of our leadership will be to take Nexter digital knowledge and experience and develop them into future leaders.

the long-term health of the Armed Forces. Goestch summarized the feeling of many Service members when he stated they "are not instilled with a sense of purpose."[101] Three naval officers assigned to the attack submarine *USS Atlanta* responded to and expanded on Goestch's article in the *US Naval Institute's Proceedings*:

> The author is right, with few exceptions, as far as he goes. But he stops his analysis at the crucial point. Junior officers are leaving the submarine force not because of what they have to put up with but because of what is lacking. A sense of purpose, duty, and station are essential to developing a sense of, and a commitment to, one's vocation. When officers leave the force, these elements are sorely lacking, if not missing altogether .... It is more than a trite patriotism or desire to serve one's country. It is a sense of professional tradition, pride, and duty, and an awareness of one's station within that profession—the feeling that no matter where you are in the chain of command, you are making a contribution.[102]
>
> **—Lieutenant (Junior Grade) John Sharpe, USN**
> **Lieutenant Commander Chris Ratliff, USN**
> **Commander Kevin Peppe, USN**

The target audience was the submarine force, but it is indicative of all Services, as well as officers and enlisted.

Leading the *Nexters* Generation

Retention of superb leaders throughout the younger Xer and the new Nexter ranks will be the toughest leadership challenge of Baby Boomers and older Xers.

Leadership and command of the Nexters is a challenge for Baby Boomers and Xers. Baby Boomers do not want to let go of the reins; Xers just now are finding their footing in a world that once overlooked them, while Nexters are technically capable of hitting the ground running in any capacity within a company or the military ranks. Followership will not be a problem for the Nexters, and they will not shrink from taking command when it is their turn. But retention of superb leaders throughout the younger Xer and the new Nexter ranks will be the toughest leadership challenge of Baby Boomers and older Xers.

Implications and Future Research

Future research should focus on how to retain Nexters and ensure they have a sense of purpose and feel like they are making a contribution.[103] As stated earlier and confirmed by all the research for this article, retention of quality military leaders to build and maintain tomorrow's Armed Forces is critical. Two surveys should be accomplished to generate data. First, Baby Boomers and Xers should be surveyed to determine retention issues impacting their decisions to stay or leave the military. Officers and enlisted, at middle through upper leadership positions, should be part of the survey to get a complete cross section of issues impacting retention. Second, Nexters should be surveyed to determine their expectations as they enter the military and retention issues impacting their decisions to stay or leave the military.

Senior leaders of today must train, inspire, and retain outstanding military leaders for tomorrow's Armed Forces. As described by the naval submariners, retention is not tied to $17K per year bonuses.[104] "A sense of purpose, real responsibility, and a chance to lead" coupled with "the feeling that no matter where you are in the chain of command, you are making a contribution."[105]

Notes

1. Rear Adm Donald R. Eaton, Retirement Speech Excerpt, 1993.
2. Ron Zemke, Bob Filipczak, Claire Raines, *Generations at Work: Managing the Clash of Veterans, Boomers, Xers, and Nexters in Your Workplace*, New York, NY: AMACOM, 2000.
3. Zemke, Filipczak, and Raines, 3.
4. *Ibid*.
5. *Ibid*.
6. *Ibid*.
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Supply Chain Management: More Than Integrated Logistics

Introduction

Logistics as a management discipline originated in the military and later branched into the commercial sector as business logistics. Now, the hottest topic in the commercial sector is supply chain management. With the Department of Defense (DoD) jumping on this latest revolution in management thought, questions arise as to what exactly is supply chain management.

This article examines the historical evolution of management thought to its newest frontier—supply chain management, reviews the emerging practices that define supply chain management in both commercial and military applications, and demonstrates that supply chain management is more than integrated logistics.

The Development of Formal Management Thought

The evolution of management thought began in a formal way with Frederick Taylor's *Principles of Scientific Management* published in 1911. Taylor focused on issues of worker productivity. In the ensuing decades, research in management practices was directed toward efficiencies in manufacturing and services (collectively referred to as operations). Beginning in the 1950s, work by Harry M. Markowitz and others spawned a thought revolution on capital markets and financial management. During the 1960s, new approaches in marketing emerged as the areas of consumer behavior and the analysis of distribution systems became the focus of much business-related research. During the decade of the 1970s, a trend which began in the 1960s—the migration of military logistics practices to the private sector—accelerated as corporations recognized the need to improve their distribution functions and American universities began to offer degree programs in logistics management.

Supply Chain Management: More Than Integrated Logistics Support

The term supply chain management was coined in 1982 by Keith Oliver, a management consultant at Booz Allen Hamilton. Oliver used the term to develop a vision for tearing down functional silos that separated production, marketing, and distribution.

New attitudes and approaches toward personnel management emerged in the 1980s as organizations recognized the importance of human resource considerations in productivity enhancement and in long-range strategic planning. The term *human resource management* was introduced. The 1980s also saw a major emphasis on quality management as US business faced increased competition from Japan.

The 1990s was a decade in which logistics management truly came of age in management thought and in private sector business practices. As the emphasis on quality matured and high quality became the standard, firms began to differentiate themselves in terms of their logistics performance. Specifically, the focus of research and practice in logistics was in terms of employing the new information technologies of the 1990s to develop capabilities and protocols for efficient and responsive material flows to meet the ever-increasing demands of customers.

The evolution of management as a discipline during the 20th century generated a body of literature and a set of practices which today define the science of management as effective, efficient planning and control of operations, finance, marketing, quality, human resources, and logistics (see Figure 1).[1]

By the year 2000, this collective maturing of management thought set the stage for a new frontier of emphasis, seeking increased customer service levels, market share, and profits by focusing on organizational interconnectivity in terms of a *supply chain*.

The Supply Chain Management Revolution

A supply chain is the sequentially-connected organizations and activities (from Mother Earth to the ultimate customer) involved in creating and making a product available. A supply chain can also be viewed as a *value chain* inasmuch as suppliers, manufacturers, transporters, and all other components of a supply chain add value. Conversely, if one looks in the reverse direction at the same activities, a supply chain can be viewed as a *demand chain*.

The term *supply chain management* was coined in 1982 by Keith Oliver, a management consultant at Booz Allen Hamilton.[2] Oliver used the term to develop a vision for tearing down functional silos that separated production, marketing, and distribution. The concept was enlarged by J. B. Houlihan in a 1985 article that expounded upon efficiencies and mutual benefits associated with information sharing and decision coordinating up and down a *supply chain*.[3]

In the late 1990s an entire culture focusing on the supply chain emerged. Universities introduced supply chain management majors or supply chain management concentrations in masters of business administration programs (Arizona State University, Syracuse University, and the University of Wisconsin, for example). Wal-Mart honed supply chain management concepts by building worldwide communication and relationship networks with suppliers to improve reliable material flows with lower inventories. Indeed, Wal-Mart is viewed by many

Years	Events
1911	**Management** emerges as a formal discipline of study and practice
1920s – 1950s	Writings on **operations**, worker productivity, and output metrics
1950s	Modern era of **finance** is launched
1960s	Modern thought in **marketing** principles and practices formulated
1970s	Accelerating trend by **business** to adopt principles of military **logistics** to distribution systems
1980s	Contemporary approaches to **human resource management** emerge **Quality** revolution
1990s	Explosive growth in logistics research and **logistics emphasis in organizations**
2000s	**Supply chain management revolution**

Figure 1. Evolution of Management Thought

as the premier practitioner of supply chain management with its demonstrated ability to get a network of worldwide suppliers, warehouses, and retail stores to behave almost "as a single firm with near real-time information…."[4,5]

By the year 2000, the trend for major organizations to establish high-level executive positions with supply chain titles was in full swing.[6]

In 2005, the Council of Logistics Management changed its name to the Council of Supply Chain Management Professionals (CSCMP).

The pervasiveness of the supply chain management revolution is skillfully described by Thomas L. Friedman in his 2005 best-selling book *The World is Flat*. He considers supply chain management and its enabling information technology revolution as being behind fundamental changes in the world economy.[7]

Defining Supply Chain Management

The supply chain management concept seeks utopian performance in commerce: all activities up and down a supply chain orchestrated and coordinated (as though a single entity) to synchronize supply and demand at all levels, the sharing of information and technologies to increase innovation and to shorten product development cycles, reduction in order cycle time, replacing stocks with flows, effectively and efficiently responding to customer demands, reduced costs, and increased customer satisfaction.

Some view supply chain management as a sophisticated new name for integrated logistics. However, supply chain management is more than integrated logistics because supply chain management involves far more than logistics.[8] Supply chains ride on the back of information systems, they include manufacturing

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Supply Chain Management: More Than Integrated Logistics Support

Stockpiles of material are viewed as generally wasteful and as hiding underlying problems such as excessive production runs, poor demand forecasting, faulty inventory data, and erroneous distribution decisions. A just-in-case attitude is replaced with a just-in-time or other lean approach as systemic process problems are eliminated.

operations, they interface with marketing and finance, and they involve such concepts as strategic sourcing, business process connectivity, risk sharing, and supplier involvement in new product development. Managing a supply chain involves activities that are outside the purview of logistics.

Figure 2 illustrates the conceptual transition from classical logistics to supply chain management, and the component parts of supply chain management. Classical logistics is concerned with the acquisition, storage, and distribution of material to get the right product to the right customer, at the right time, at the right place, in the right condition, in the right quantity, at the right cost (the *Seven R's of Logistics*).

Modern logistics, along with modern manufacturing, has moved beyond classical activities by incorporating lean practices. Here the focus is on more than just time and place utility. Lean logistics and lean manufacturing emphasize flows rather than stocks. Stockpiles of material are viewed as generally wasteful and as hiding underlying problems such as excessive production runs, poor demand forecasting, faulty inventory data, and erroneous distribution decisions. A just-in-case attitude is replaced with a just-in-time or other lean approach as systemic process problems are eliminated. In short, inventory is replaced with information in the form of real-time demand (point of sale data, for example), more accurate forecasts, and visibility on inventory location.

As illustrated in Figure 2, lean logistics and lean manufacturing become two of the five components of supply chain management. Contrary to a popular view that supply chain management is just super-charged logistics, the cornerstone of supply chain management is not logistics. Alliances with key partners, and information technology that allows supply chain partners to share accurate

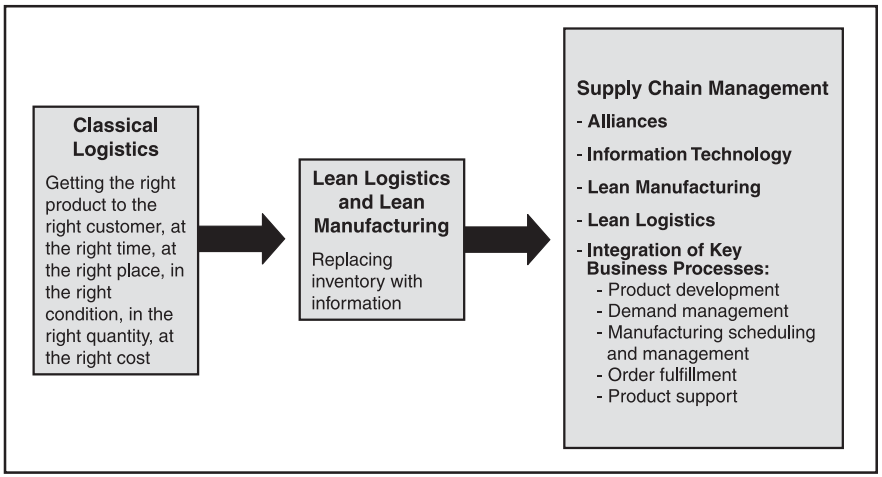

Figure 2. Conceptual Transition from Classical Logistics to Supply Chain Management

information on a timely basis are the building blocks of efficient and responsive supply chain operations.[9] Upon this foundation, the introduction of lean manufacturing and lean logistics processes, together with the integration of key business processes up and down the supply chain create supply chain management.

Alliances are collaborative relationships with key partners built upon trust. In alliances, upstream partners are more than sources. They are resources to the focal firm for problem solving, and for innovation (new technologies for example). With alliances, partners are viewed as extensions of the focal firm and decisions are made in the context of mutual gain. Such collaboration is the underpinning of supplier relationship management (upstream) and customer relationship management (downstream).

Information technology is the glue that holds the supply chain together. The functional areas within the firm operate from a common, shared database. Alliance partners share data. The accuracy, the speed, the relevance, the availability, and the accessibility of information are critical for successful supply chain performance.

Supply Chain Information Systems

Information systems supporting supply chain operations are of four categories:

- **Enterprise resource planning (ERP) software.** ERP software processes all transactions in every functional area and provides real-time access to an enterprise-wide data base. ERP replaces the legacy information systems which through the years have been cobbled together by operations, finance, marketing, engineering, procurement, and so forth. Legacy systems are capability inhibited, difficult to connect to other functional areas, and cannot support supply chain dynamics.
- **Electronic data interchange (EDI) or Internet connectivity.** EDI and the Internet facilitate an interconnected business environment that allows partners to share decision-relevant information up and down the supply chain.
- **Electronic product code (EPC) technologies.** EPC technologies include bar codes, optical scanners, and radio frequency identification (RFID) technologies. EPC allows for item, case, pallet, and vehicle tagging for a *track and trace* capability in a supply chain.
- **Supply chain analytics (SCA).** SCA is any software designed to assess and improve supply chain performance. SCA can do such things as evaluate capacity, materials, and customer demand imbalances; or identify which carriers and distribution centers are most responsive.

Information technology is the glue that holds the supply chain together.

Integrating Business Processes

The final component of supply chain management is that which makes a supply chain operational—integration of key business processes among the players up and down a supply chain.

Supply Chain Management: More Than Integrated Logistics Support

Coordination of manufacturing scheduling and management throughout a supply chain occurs with sharing of business plans and real-time inventory and demand information, and with an integrated business process of collaborative planning and forecasting.

Product Development

The objective of the product development process is bringing state-of-the-art products that meet customer wants and needs to market faster than the competition. This happens with internal integration of functions, and upstream and downstream involvement of supply chain partners.

In a supply chain management environment, engineering, manufacturing, procurement, logistics, marketing, and suppliers (and sometimes customers) work synergistically in cross-functional teams during product development.

Suppliers, viewed as resources, are involved early in the design stage of a new product. Suppliers (including supplier's suppliers) contribute information on new materials, new technologies, design engineering, process engineering, value analysis, supportability issues, and cost management. Early supplier involvement means shortened product development cycles and faster time to market of superior products.

Downstream, customers are often brought into the process through collaboration to understand their performance and design requirements, as well as their demand patterns.

Demand Management

Modern supply chains are customer-driven pull systems. The focal firm's supply capabilities must be synchronized with known and forecasted demand patterns of downstream customers. The buy-make-move functions at all levels of a supply chain are driven by real-time demand data or by meaningful, current, adaptable forecasts that reduce uncertainty and promote responsive material flows throughout the supply chain. Such a process allows for higher levels of customer service with reduced inventories.

Manufacturing Scheduling and Management

Coordination of manufacturing scheduling and management throughout a supply chain occurs with sharing of business plans and real-time inventory and demand information, and with an integrated business process of collaborative planning and forecasting. The supply chain concept requires movement away from the old, industrial economy mindset of *make to stock* to the information-age economy which means production at all levels reflects demand and supply synchronization.

Order Fulfillment

Real-time visibility on inventory quantity and location, collaborative processes, and shared data foster flexible and responsive management of customer orders across global supply chains. Supply chain capabilities allow for seamless, continuous replenishment systems that meet or exceed customer expectations.

Product Support

The supreme goal of supply chain management—effective, efficient customer service with superior products and service—requires a network of activities for

responsive, after-sale product support. This includes high service levels for spare and repair parts, technical data, maintenance and calibration services, warranties, and returns.

In sum, by formula we can define Supply Chain Management as:

Alliances + Information Technology + Lean Manufacturing + Lean Logistics + Integration of Key Business Processes

Figure 3 contrasts characteristics of classical logistics with pure supply chain management. To be sure, these are comparisons of extremes. Classical logistics does not represent information-age or modern, lean practices. Pure supply chain management is an ideal based upon levels of trust, risk, and information purity that are not descriptive of all situations and environments. Nonetheless, this comparison highlights the evolving characteristics of a management revolution called supply chain management.

Evolution from Logistics to Supply Chain Management

Figure 4 graphically portrays the evolution of logistics thought and practice.

Although logistics activities parallel the conduct of war and have existed for thousands of years, the term appears to have received its first official definition in 1905.[10]

Logistical activities on a massive scale occurred during World War II as huge stockpiles of materiel were pushed into theaters. The industrial-age *iron mountain* approach was the sure way to provide strategic support to military forces.

During the 1950s, two factors forced a consideration of *efficiency* in addition to effectiveness in providing logistical support to armed forces. First, the two Hoover Commissions (Commissions on the Organization of the Executive Branch of the Government) and congressional inquiries into military supply management during the Korean War identified waste and inefficiencies in military procurement and logistics. These findings spawned efficiency initiatives by the Department of Defense (DoD) that included creation of the first, single DoD-wide logistics executive (Assistant Secretary of Defense for Supply and Logistics); separate management approaches for *repairables* (now called *reparables*) and *consumables*; introduction of the item manager concept; and efforts toward standardization for items common to the three Services.[11]

Second, major challenges associated with America's first supersonic bomber, the B-58, manifested the need to consider maintainability in design of weapon systems. Not only did engineering complexities of the B-58 make it difficult to fly, flying-hour costs were huge, and maintenance intricacies required inordinate training and skill levels and highly specialized equipment. In 1965 early retirement was ordered for this aircraft. The B-58 demonstrated the need for configuration management; reliability and maintainability engineering, and life-cycle cost management to be included in the field of logistics.[12]

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Supply Chain Management: More Than Integrated Logistics Support

During the 1960s, an engineering perspective was added to the management aspect of logistics. Logistics became a quantitative science. The principles underlying logistics support analysis and integrated logistics support emerged.

The systems approach to logistics matured in the 1970s and 1980s. The art and science of logistics was treated as a set of interrelated activities. In 1970, logistics engineers and provisioning specialists from Air Force Logistics Command (AFLC) were, for the first time, collocated with a system program office in Air Force

The systems approach to logistics matured in the 1970s and 1980s.

	Classical Logistics	Pure Supply Chain Management
Starting point	Requirements determination	Business process renovation
Organization	Functional silos	Integrated supply chain
Strategy	Predetermined plans of action	Adaptive capabilities for flexible response
Span of vision	First tier sources and customers	End-to-end system
Management focus	Logistics optimization	Extended enterprise optimization
Performance standards	Provider-developed	Customer-dictated
Partner selection	Quote and competition	Proposal and negotiation
Partner connectivity	Short-term contracts	Long-term contracts and strategic alliances
Contractual environment	Legalistic	Institutional trust
Relationships	Transactional; arms length	Long term, collaborative
Relationship objective	Opportunistic advantage	Mutually satisfactory outcome with emphasis on continuity of the relationship
Procurement objective	Contract compliance at minimum cost	Best value (innovation, quality, service, and price)
Supplier base	Huge	Circumscribed to select or world-class suppliers
View toward supplier	Source	Resource
Material verification	Material inspections	Certified suppliers
Business environment	Adversarial	Mutual gain
Transportation approach	Service objective at minimum cost	Consistent, reliable, responsive service
Inventory approach	Push system; just-in-case	Pull system; replace inventory with information
Material flows	Scheduled	Self-synchronizing
Information	Industry standards, performance audits, status and exception reports	Enterprise resource planning system, electronic product codes, Internet connectivity, and supply chain analytics
Cost and service	A trade-off	Reengineer processes to increase service levels and reduce costs
Cost focus	Acquisition cost	Total cost of ownership
Support asset focus	Stocks	Flows
Risk	Low	Higher

Figure 3. Comparative Characteristics of Classical Logistics and Supply Chain Management

Systems Command (AFSC).[13] In 1976 AFLC created the Acquisition Logistics Division to work closely with AFSC to promote maintainability and support of weapons systems and ancillary equipment.[14] This era saw a major push on design for maintainability, supportability, and life-cycle cost management.

In 1992, AFLC and AFSC were merged into Air Force Materiel Command. This merger strengthened the systems view of logistics by marrying the research, science, engineering, and acquisition strategy expertise of AFSC with the logistics engineering and management expertise within AFLC. The Agile Combat Support (ACS) doctrine became the targeted core competency for Air Force logistics. Program managers were given a *cradle-to-grave* responsibility for their acquisition programs as part of the integrated weapons systems management (IWSM) philosophy.[15]

On the commercial side of logistics, the marketing profession began to look at principles of military logistics as a way to improve distribution in the private sector in the mid-1960s. By the 1980s and 1990s, business logistics (defined as a customer-driven order fulfillment process with nine dimensions, as portrayed in Figure 4) became an important area for corporate strategy.

The 1990s also saw the blossoming of the information age, which offered the facilitating technologies for the supply chain management revolution of the 21st century.

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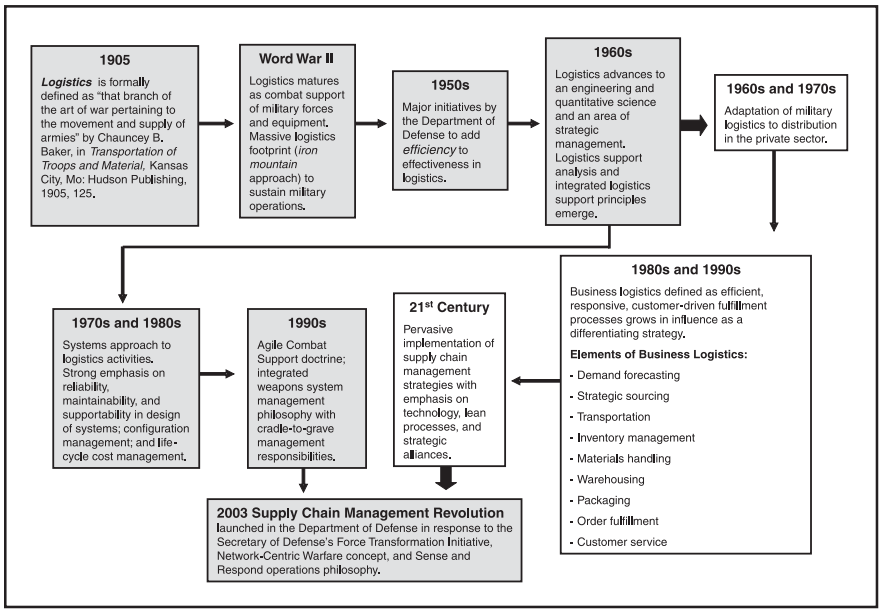

Figure 4. Evolution of Logistics Thought and Practice

Supply Chain Management: More Than Integrated Logistics Support

The supply chain transformation within the US Air Force was formally launched in 2003 with the Expeditionary Logistics for the 21st Century campaign.

Supply Chain Management in the US Military

The private sector borrowed best-practice concepts in military logistics beginning in the 1960s. The defense establishment is now implementing commercial best practices by pursuing the concepts, practices, and technologies of supply chain management.

Although DoD created a supply chain executive position in 1998 (Deputy Under Secretary of Defense for Supply Chain Integration), a supply chain management campaign by the Office of the Secretary of Defense (OSD) was not launched until 2003.[16]

The impetus for this campaign was Secretary of Defense Donald H. Rumsfeld's 2001 initiative to transform US military capabilities and the establishment of the Office of Force Transformation (OFT).[17] Arthur K. Cebrowski, OFT's first director, developed the guiding philosophy of the transformation which he called network-centric warfare (NCW). NCW is best viewed as a theory of war in the information age. Information sharing among networks of intelligence, operations, and logistics communities facilitates speed of command, flexible and situational response, and sustainability.[18]

As part of the NCW model, OFT unveiled the Sense and Respond Logistics (S&RL) initiative in 2003.[19] S&RL is a philosophical umbrella for military supply chain management. It is a strategy for developing supply chains with players, information systems, capabilities, and protocols to respond rapidly to changing combat support requirements in the field. The *sense* aspect of S&RL is a real-time information system for gathering demand signals from the field. *Respond* is capabilities for flexible and speedy action within end-to-end supply chains. In short, S&RL is about the use of networks and sensors to create an agile supply chain with total asset visibility and real-time support capability. In an S&RL world, logistics mass is replaced with logistics speed.[20]

Responsibility for the S&RL project has been given to the Office of the Undersecretary of Defense for Acquisition, Technology and Logistics. Their mandate is to pursue the underlying technologies and to work with the individual military departments to identify and develop their potentials for S&RL.[21]

In the interim, OSD has directed the implementation of modern supply chain practices for all DoD components. The DoD supply chain materiel management regulation (DoD 4140.1-R dated 23 May 2003) mandates a supply chain framework and guiding principles for: effective and efficient end-to-end material support, meeting customer expectations while minimizing inventories, promulgating supply chain best practices in material management, and establishing the customer as the foundation driving all material management decisionmaking. This regulation requires all DoD components to measure total supply chain performance.[22]

The supply chain transformation within the US Air Force was formally launched in 2003 with the Expeditionary Logistics for the 21st Century (eLog21) campaign.

The goal of eLog21 is, by philosophy, to offer efficient, agile combat support; by vision, an enterprise view of logistics; and in practicality, to use supply chain concepts and technology to improve weapons availability by 20 percent and to reduce support costs at the same time.[23]

The eLog21 program contains all the elements of modern supply chain management. Fulfillment processes are being reengineered to increase customer service and to reduce costs. Revised and integrated business practices for sustainment mirror private sector best practices. RFID is being extensively employed for asset tracking. And major investment in supporting information technology, the Expeditionary Combat Support System (which is the Air Force version of enterprise resource planning technology used in the private sector) is programmed.

Summary

Integrated logistics in a commercial context is coordinating logistics activities with other functional areas of the firm and with customers and suppliers. In a military context, integrated logistics is designing reliability, maintainability, and supportability into weapon systems, focusing on customer requirements, and coordinating supply support, training, technical data, and all other integrated logistics support elements.

Supply chain management is more than integrated logistics. Supply chain thinking represents a major breakthrough in thought about the interconnectivity of information technology, logistics processes, and customer support. Supply chain management is alliances with supply chain partners, lean processes, and end-to-end integration of key business processes. The enabling technology is information.

Supply chain management is more than integrated logistics. Supply chain thinking represents a major breakthrough in thought about the interconnectivity of information technology, logistics processes, and customer support. Supply chain management is alliances with supply chain partners, lean processes, and end-to-end integration of key business processes.

Supply chain management is more than a passing stage in the continuing evolution of management practice. It is a major revolution which is already delivering end-to-end visibility, cost reductions, and new levels of performance metrics in meeting customer requirements.

Notes

1. "Historical Background of Organizational Behavior," [Online] Available:http://web.cba.neu.edu/~ewertheim/introd/history.htm, accessed 2 Apr 2007). Another element in the evolution of management thought is that of human motivation and the relationship between work environment and productivity. This field of inquiry (called organizational behavior) originated with the famous Hawthorne Studies on worker productivity in the 1920s and advanced with such notable contributions as Maslow's Hierarchy of Needs (1950s) and Douglas McGregor's human relations approach to management called Theory X and Theory Y (1960s).
2. Keith Oliver, "When Will Supply Chain Management Grow Up?" *Strategy + Business*, Fall 2003, Issue 32, [Online] Available: www.strategy-business.com/press/16635507/03304, accessed 23 Apr 2007.
3. J.B. Houlihan, "International Supply Chain Management," *International Journal of Physical Distribution and Materials Management*, Vol 15, No 1, 1985, 51-56.

Supply Chain Management: More Than Integrated Logistics Support

4. Scott Webster, *Principles and Tools for Supply Chain Management*, Boston, MA: McGraw-Hill-Irwin, 2008, 7.
5. Thomas L Friedman, *The World is Flat: A Brief History of the Twenty-First Century*, New York, NY: Farrar, Straus and Giroux, 2006, 151. Friedman characterizes Wal-Mart's efficient global supply chains as "The Wal-Mart symphony in multiple movements—with no finale."
6. Early examples include Kraft Foods, The Home Depot, Fairchild Semiconductor, Logitech, Delta Airlines, Whirlpool Corporation, Tyco International, and General Motors.
7. Thomas L Friedman.
8. Nonetheless, the intellectual home for the supply chain management revolution has been in logistics. Logisticians lead this movement. The logistics managers at Wal-Mart, for example, spearheaded the move to supply chain management in that organization. The leading-edge thinkers in the supply chain revolution (Douglas M. Lambert of Ohio State University, James R. Stock of the University of South Florida, and John T. Mentzer of the University of Tennessee, for example) are logisticians by background.
9. This thought appears to have been advanced first by Douglas M. Lambert of Ohio State University and director of the Global Supply Chain Forum. See Douglas M. Lambert, *Supply Chain Management: Processes, Partnerships, and Performance,* 2d Edition, Sarasota, Florida: SCM Institute, 2006.
10. Chauncey B. Baker, *Transportation of Troops and Material*, Kansas City, MO: Hudson Publishing, 1905, 125. For an expanded discussion on the origin of the term *logistics* and for various definitions, see Stephen Hays Russell, "The Growing World of Logistics," *Air Force Journal of Logistics*, XXIV, No 4, 15-19.
11. See "History of the Defense Logistics Agency," [Online] Available: www.dla.mil/history, accessed 18 Feb 2007.
12. For an example, see "B-58 Hustler," [Online] Available: www.globalsecurity.org/wmd/systems/b-58-fc.htm, accessed 18 Feb 2007.
13. In 1970, the B-1 System Program Office (SPO), as part of an initiative dubbed *Innovations*, colocated SPO personnel (engineers and program control people) at contractor sites (North American Rockwell in Los Angeles and General Electric Aircraft Engine Group in Evendale, Ohio). The SPO also had AFLC collocate personnel in these satellite SPOs.
14. *The Logistics of War: A Historical Perspective*, Maxwell AFB, Gunter Annex, AL: Air Force Logistics Management Agency, 2000, 360.
15. Although intended for acquisition programs, the IWSM philosophy was expanded to product and materiel managers. The objective was to create a seamless process for spares by integrating the acquisition and sustainment processes.
16. In April 2003, OSD charged the Services with a series of supply chain transformation objectives including reengineering logistics processes, total asset visibility, and time-definite delivery. The individual Services, however, were pursuing supply chain concepts prior to that date. The Air Force Purchasing and Supply Chain Management (PSCM) project was initiated in February 2001 and progressed to its current design in April 2004. The Expeditionary Logistics for the 21st Century (eLog21) program, of which PSCM is a component and the Air Force approach to supply chain transformation, began in February 2003. For a comprehensive overview of the eLog21 program see, *Expeditionary Logistics for the 21st Century Campaign Plan*, [Online] Available: www.af.mil/shared/media/document/AFD-060831-041.pdf, accessed 30 Mar 2007.
17. See "Office of Force Transformation Homepage" [[Online] Available: www.oft.osd.mil, accessed 18 Feb 2007.
18. D. S. Alberts, J.T. Garstka, and F.P. Stein, *Network Centric Warfare: Developing and Leveraging Information Superiority*, 2d ed (Revised), Washington, DC: CCRP Publications, Aug 1999, [Online] Available: www.dodccrp.org/files/alberts_ncw.pdf, accessed 18 Feb 2007.
19. Sense and respond as a business philosophy was developed by Stephan H. Haeckel of the IBM Advanced Business Institute in 1993. See S.H. Haeckel and A.J. Slywotsky, *The Adaptive*

Enterprise: Creating and Leading Sense and Respond Organizations, Harvard Business School Press, 1999; and "Operational Sense and Response Logistics: Co-evolution of an Adaptive Enterprise Capability," Office of Force Transformation, Nov 2004, [Online] Available: www.oft.osd.mil/Initiative/srl/S&RL_Concept_Short.doc, accessed 12 Mar 2007.

20. For an excellent treatment of the Sense and Respond model see Karen Butner, et al., *Reshaping Supply Chain Management: Vision and Reality*, Boston, MA: Pearson Custom Publishing for IBM Global Business Services, 2007.
21. An insightful discussion on the progress and the challenge of organizational change in moving DoD components to S&RL is found in Heather B. Hayes', "Sense and Respond in Fits and Starts," *Defense Systems*, Sept/Oct 2006, [Online] Available: www.defensesystems.com/issues/1_5/features/474-1.html, accessed 11 Apr 2007.
22. Office of the Deputy Under Secretary of Defense for Logistics and Materiel Readiness, *DoD 4140.1-R DoD Supply Chain Materiel Management Regulation*, 23 May 2003, [Online] Available: www.ditc.mil/whs/directives/corres/pdf/414001r.pdf, accessed 2 Jan 2007.
23. "eLog21 Fact Sheet," [Online] Available: https://acc.dau.mil/CommunityBrowser.aspx?id=32774, accessed 2 Mar 2007; "eLog21 Purchasing and Supply Chain Management," *Air Force Journal of Logistics*, 23 May 2003, [Online] Available: www.accessmylibrary.com/coms2/summary_0286-1448758_ITM, accessed 2 Mar 2007.

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Earned Value Management: Uses and Misuses

Introduction

Earned Value Management (EVM)was originally developed by the United States Air Force as a financial management tool. Over the years, the earned value technique has matured into a significant project management tool with particular application to the acquisition of weapon systems.

The relevance of EVM to the logistics community is threefold. First, today's logisticians are intimately involved in the weapon systems acquisition process. Because EVM is such an integral part of the imposed acquisition management architecture, logisticians need to understand the tool. Otherwise, they become tangential to the management and performance reviews of an acquisition program. Second, EVM is increasingly being addressed in the literature of performance based logistics (PBL) and acquisition logistics.[1] Third, EVM as a leading-edge management tool has not seen the application to logistics-specific projects that it merits.[2]

Many logisticians have low familiarity with this important management tool. This article examines the conceptual underpinnings of the EVM methodology and its applicability to measuring a project's performance, with particular emphasis on its uses and misuses.

Background of EVM

The earned value concept was developed to correct serious distortions in assessing a project's cost performance generated by comparing actual costs with a time-phased budget. Consider Figure 1, which plots both a time-phased budget (the spend plan)

and cumulative actual expenditures to date. Note that at Time $_{Now}$, actual expenditures are below budget. Cost performance *appears* favorable.

The problem, of course, is this approach fails to consider what work has been done. The cumulative budget at Time $_{Now}$ may contemplate the completion of more tasks than have actually been accomplished. If this is the case, the favorable cost variance could be illusionary.

A more accurate assessment—one that ties budget to tasks actually completed—is possible with the time-phased program plan.

A more accurate assessment—one that ties budget to tasks actually completed—is possible with the time-phased program plan illustrated in Table 1. Here four tasks have been scheduled to date for a total Time $_{Now}$ budget of $152K. Actual expenditures to date are $128K. However, only Tasks A, B, and C have been accomplished. Hence, comparing the $128K actually spent to the $152K spend plan does not make sense. Why? Because this program is behind schedule. Task D has not been accomplished as of Time$_{Now}$. The *earned value* to date—earned in the sense that the tasks have been performed—is $120K. Clearly, we should compare expenditures to date to the earned value. With this comparison, we correctly determine that this project is $8K over budget ($128K spent less $120K budgeted for the tasks actually completed), whereas the spend plan approach suggested by Figure 1 would erroneously conclude this program is under budget by $24K ($152K - $128K). This earned value concept is at the heart of EVM.

The following discussion illustrates that EVM brings together the scope, budget, and cost dimensions of a project and generates metrics for planning, measurement, and control.

EVM Techniques

Earned Value Management requires four pieces of information:

- A baseline plan that defines the project in total
- The tasks planned to be accomplished at Time $_{Now}$
- The budgeted value of the tasks accomplished by Time $_{Now}$
- Actual costs at Time $_{Now}$

The baseline plan is the entire project defined by objectives, tasks, and budget. The aggregated budget for all tasks is called the budget at completion (BAC) and represents the approved funds or the budget constraint for the entire project.

The sum of all tasks in the baseline plan you planned to have accomplished at Time $_{Now}$ in budgeted dollars is called the budgeted cost of work scheduled (BCWS) in EVM terminology. BCWS is the planned value. In Table 1 this value is $152K.

The budgeted value of the tasks actually completed at Time $_{Now}$ is the earned value to date and is called the budgeted cost of work performed (BCWP). In Table 1 this value is $120K.

How much you have actually spent to date is called actual cost of work performed (ACWP). In Table 1 this value is $128K.

As suggested earlier, the key piece of information in EVM and the basis for the EVM technique is the earned value, which is BCWP. In all EVM analysis, BCWP is a benchmark number for variance and performance measures.

The Metrics of Performance Measurement

The difference between BCWP and ACWP (that is, the difference between the budgeted cost through Time $_{Now}$ and the actual cost at Time $_{Now}$ for the work performed) is the cost variance (CV). In the Table 1 example, CV is -$8K ($120K - $128K).

The difference between BCWP and BCWS (that is, the difference between the work you have performed and the work you have scheduled through Time $_{Now}$ on a budgeted basis) is schedule variance (SV). In Table 1, SV is $-32K ($120K - $152K).

These performance measurements are expressed formally as:

1. CV = BCWP - ACWP
2. SV = BCWP - BCWS

Task	Budget	Status	Actual
A	$40K	Done	$42K
B	$60K	Done	$60K
C	$20K	Done	$26K
D	$32K	Pending	
Total at Time$_{Now}$	$152K		$128K

Table 1. Tasks Scheduled Through Time$_{now}$

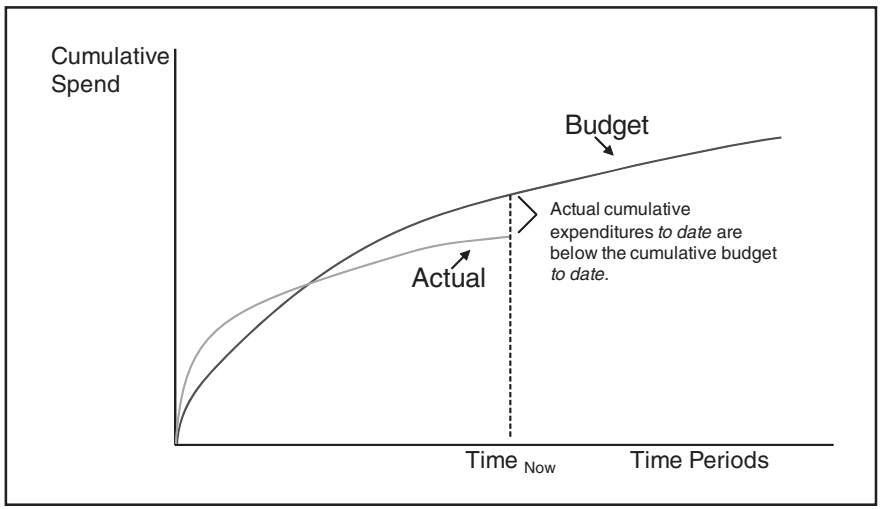

Figure 1. The Spend Plan Approach

Earned Value Management requires four pieces of information:
1. a baseline plan that defines the project in total,
2. the tasks planned to be accomplished at Time $_{Now,}$
3. the budgeted value of the tasks accomplished by Time $_{Now,}$ and
4. actual costs at Time $_{Now.}$

Earned Value Management: Uses and Misuses

EVM can be successfully employed in varying degrees of formality and in projects of all sizes. Examples of potential logistics applications of EVM include a complex logistics research project, development and implementation of new software, design and construction of a new maintenance facility, or any other complex project whose plan consists of discrete, time-phased tasks.

Note that in both CV and SV calculations the benchmark for measurement is the *earned value*—that is, the BCWP. For these variance measures, positive values portray the project as doing better than planned. Specifically, if for work performed, *actual cost* is less than *budgeted cost*, CV is positive—meaning actuals are less than budget, a favorable condition. For SV, if on a budgeted basis *work performed* is greater than *work scheduled*, a positive value means the project is ahead of schedule. Similarly, negative values portray unfavorable conditions.

Consider Figure 2. BCWP or earned value (the work actually performed on a budgeted basis) is ahead of BCWS (the work scheduled on a budgeted basis) at Time_{Now}. This project is ahead of schedule. However, for the work performed, actual cost at Time_{Now} (ACWP) exceeds the budgeted cost (BCWP). This project is experiencing a cost overrun. Indeed, in this example, actual cost will soon reach the BAC constraint—the cumulative BCWS for the whole project. Clearly, action is required by the program manager.

Performance can also be expressed in terms of ratios. The ratio of BCWP to ACWP is the cost performance index (CPI):

3. CPI = BCWP/ACWP

The ratio of BCWP to BCWS is the schedule performance index (SPI).

4. SPI = BCWP/BCWS

For these ratio measures, values greater than 1.0 mean performance is favorable (better than the plan).

Implementing EVM

EVM can be successfully employed in varying degrees of formality and in projects of all sizes. Examples of potential logistics applications of EVM include a complex logistics research project, development and implementation of new software, design and construction of a new maintenance facility, or any other complex project whose plan consists of discrete, time-phased tasks.

Implementation requires the establishment of detailed processes to collect baseline data and to reliably measure performance and cost. For Department of Defense (DoD)-compliant systems (that is, for EVM systems of private sector firms to qualify for defense contracts), the implementation must satisfy 32 official structural and measurement criteria jointly developed by the federal government and industry.[3]

The first step in implementation is identifying the total scope of work that defines the project and creating a master schedule and a budget for project accomplishment. This step defines the scope baseline in tasks, time, and dollars. The scope baseline is the time-phased BCWS, the project's planned value. The project's total budget (the BAC) is the BCWS for the whole project.

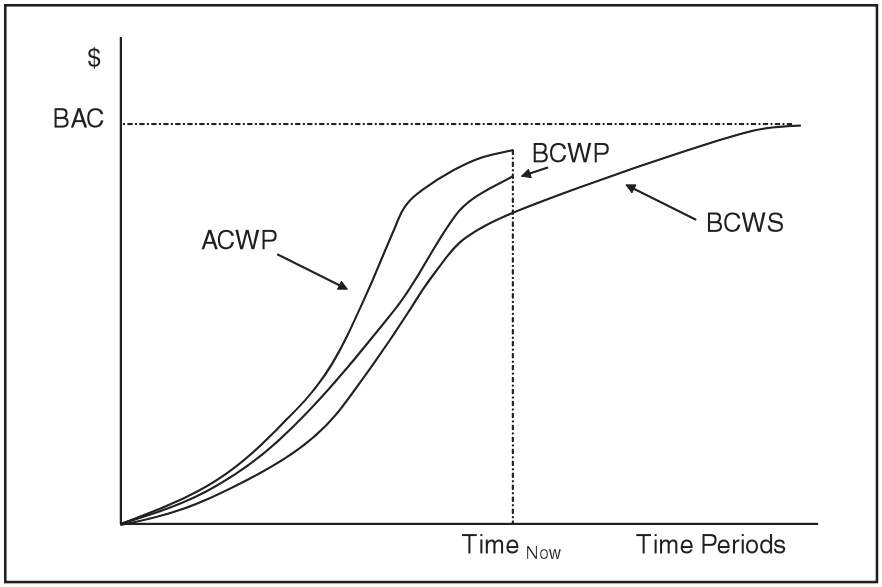

Figure 2. Illustration of EVM Metrics

Next, the baseline is broken down into miniature project plans called control account plans (CAPs) (see Figure 3). Each CAP will have a programmed start and completion date, an assigned hour and dollar budget, and assigned resources including a manager accountable for accomplishment.

CAPs are, in turn, disaggregated into discrete work packages. It is at the work package level where earned value is measured and reported at the CAP and ultimately the project level.

The work package level is the genesis for a bottom-up approach to program performance in terms of BCWS, BCWP, and ACWP. Once the project has begun, performance measurement and variance analysis is launched at the work package level and rolled up into the CAP and total program level.

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Uses and Misuses of EVM

To illustrate the uses and potential misuses of EVM, consider the metrics portrayed in Figure 4. At Time_{Now}, ACWP exceeds BCWP. The distance CV represents cost overrun to date.

Figure 4 also shows BCWP below BCWS. On a dollarized basis, this program is behind schedule by the amount of SV.

The time dimension of the behind-schedule condition (labeled *Time Variance* in Figure 4) is illustrated by the horizontal distance between BCWS and BCWP. At Time_{Now}, the dollar value of work performed (BCWP) should have been achieved at the time period indicated by that same value on the BCWS line.

Earned Value Management: Uses and Misuses

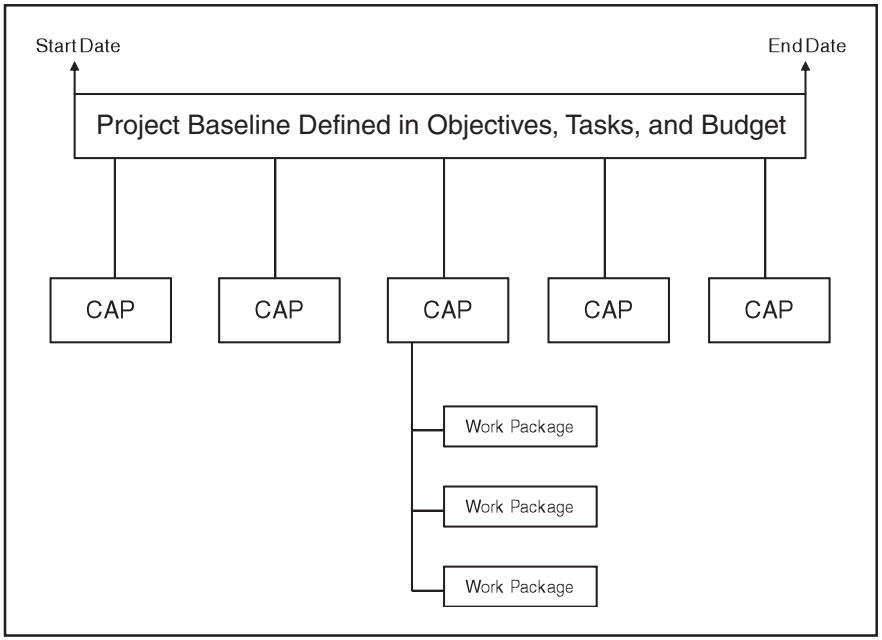

Figure 3. Data and Measurement Structure for Implementing EVM

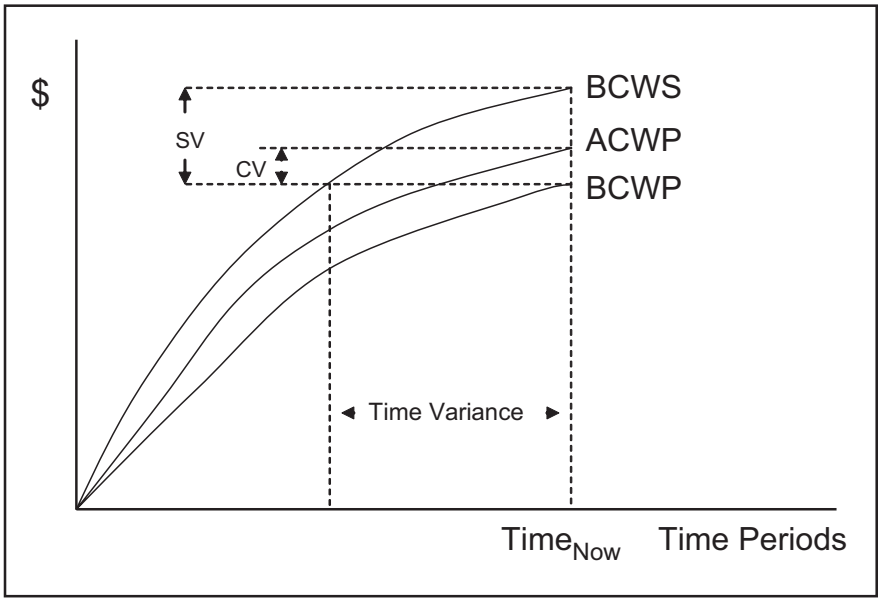

Figure 4. Performance Assessment with EVM Metrics

These performance measures serve the following purposes:

- They can serve as an early warning to the program manager that this program is in trouble. In the Figure 4 example, both variance measures are negative, meaning this program is both behind schedule and over on cost.
- Managers can *drill down* to CAPs and work packages in the EVM database to identify areas and root causes of schedule slippage and cost overruns.
- Constructive actions can be taken as EVM metrics indicate deviations from plan. Actions may include correcting inefficiencies that caused the deviations, the recognition that initial budgets were inadequate for the scope of work programmed, or the application of additional resources to bring the project back on schedule. Conversely, unfavorable schedule and cost performance at Time_{Now} may force the program manager to take tasks out of the project (bring the scope of the total project down) in order to complete the program within a firm BAC.
- Program status at completion can be projected. The CPI can be employed to develop a revised estimate on cost to complete the program. Note from equation 3 the CPI is the ratio of BCWP to ACWP. Assume this value is .90. This means that for every dollar spent, only 90 percent of the programmed work for that dollar is actually getting accomplished. If we assume the CPI to date is indicative of future performance (that is, that the CPI will remain reasonably stable for the duration of the project), then we can use the following equation for an estimate at completion (EAC) calculation:

5. EAC = BAC/CPI

In logic, this equation reduces to the simple proposition that if actual costs are running 11.1 percent ahead of budget for work to date (1.0 divided by .90), a reasonable EAC will likely be 11.1 percent greater than the BAC.

With regard to schedule performance, the SPI given in equation 4 divides BCWP by BCWS. Assume this value is .85. For every dollar of budget (BCWS) only 85 cents worth of work gets completed (BCWP). The inverse of the SPI (BCWS/BCWP) in this example (1.176) would indicate this project is running 17.6 percent behind schedule or that the project is forecasted to take 17.6 percent longer than the original schedule.

These illustrations represent the common employment of EVM to assess the cost and schedule performance of a project. However, rote employment of these metrics is risky and can represent a misuse of EVM—misuse in the sense that these metrics must not be employed in a vacuum or to the exclusion of other performance indicators.

First, consider cost performance metrics. The EAC of equation 5 assumes the remaining work will have the same relative cost variance as work already done.[4] Analysis of root causes or of specific CAPS may show that past performance is not a good predictor of future performance—that a particular problem will not occur again.[5]

Earned Value Management: Uses and Misuses

The most significant misuse of EVM, however, is in the area of schedule assessment. Using SV as the only measure of schedule performance can lead to erroneous conclusions. For example, some tasks may be performed out of sequence. High-dollar activities may be done ahead of schedule while lesser value critical activities are hopelessly behind schedule.

Furthermore, if the project is behind schedule, project duration increases and so will costs. Efforts to get the project back on schedule usually mean the employment of more resources (overtime, for example). In short, to project costs without incorporating the cost implications of a schedule variance is a misuse of EVM metrics as well.[6]

The most significant misuse of EVM, however, is in the area of schedule assessment. Using SV as the only measure of schedule performance can lead to erroneous conclusions. For example, some tasks may be performed out of sequence. High-dollar activities may be done ahead of schedule while lesser value critical activities are hopelessly behind schedule. Yet, EVM will show a favorable SV at the project level. A project in aggregate may be ahead of schedule, yet one critical component may not be available. In this situation, heads-up managers know delivery schedules will slip, yet EVM will show this program ahead of schedule.[7]

A quirk of EVM is the fact that every project (even a project behind schedule) shows an SV metric of zero at project completion. This happens because as the project approaches 100 percent completion, the work performed (BCWP) converges on the work scheduled (BCWS)—no more variance. Obviously, at some point prior, the SV as a performance metric has lost its management value.

Clearly, program managers need a schedule management system that is sequence- and milestone-based. EVM may be an aggregate indicator of work performed compared to work scheduled, but to engage EVM as a reliable schedule indicator is a misuse of the tool.[8]

Conclusion

Over the years, a number of significant management innovations and tools with broad application have emerged from the DoD. These include incentive contracting, Performance Evaluation and Review Technique (PERT), configuration management, integrated logistics support, life-cycle costing, and many others. One major tool developed by DoD that continues to face limited familiarity within the logistics community is EVM.

A basic understanding of EVM is important to the logistician, not only because of its intrinsic value to the management of any complex project, but because it is now widely employed in the procurement-program management community of which logistics is a part.

EVM is able to provide a true picture of a project's cost performance by accounting for differences between work accomplished and work scheduled. A number of metrics are employed for variance calculations, performance indices, and projections at completion.

Originally developed as a financial management tool, EVM has become a project management tool for cost, schedule, and scope management. However, this broader

approach to EVM generates potential for misuse when the schedule metrics of EVM are used to the exclusion of true schedule management tools. In addition, EAC calculations with EVM metrics should be employed judiciously lest misleading projections arise given the circumstances of any particular project.

This article equips the logistician with an understanding of the terminology and technique of EVM, and provides an appreciation for its uses and potential misuses.

Notes

1. EVM is now an integral part of DoD's guidelines on PBL. See *Performance Based Logistics: A Program Manager's Product Support Guide*, Defense Acquisition University, Mar 2005, [Online] Available: http://www.dau.mil/pubs/misc/PBL_Guide.pdf, accessed 28 Apr 2008.
2. The best opportunities for [EVM] may well lie in the management of thousands of smaller projects that are being directed by people who may well be unaware of earned value. Quentin W. Fleming and Joel M. Koppelman, "Earned Value Project Management: A Powerful Tool for Software Projects," *Crosstalk: The Journal of Defense Software Engineering*, Jul 1998, 23, [Online] Available: http://www.stsc.hill.af.mil/crosstalk/1998/07/value.asp, accessed 11 Nov 2007.
3. The 32 standards have evolved into an American National Standards Institute (ANSI) standard on *Earned Value Management System Guidelines*, ANSI/EIA-748-A-1998 (R2002). Copies can be ordered from Global Engineering Documents (800-854-7179). DoD policy and guidance on EVM are online and available at www.acq.osd.mil/pm.
4. For a complete assessment of this issue, see David Christensen and Kirk Payne, "Cost Performance Index Stability—Fact or Fiction?" *Journal of Parametrics,* 10 Apr 1992, 27-40, and David S. Christensen, "Using Performance Indices to Evaluate the Estimate at Completion," *Journal of Cost Analysis and Management*, Spring 1994, 17-24.
5. Different shops, different work forces, different subcontractors, and different cost problems within a project don't necessarily invite a mirrored projection of past performance into the future. And cost variances in production don't necessarily mean similar variances in assembly.
6. Jan Evensmo and Jan Terje Karlsen, "Reviewing the Assumptions Behind Performance Indexes," *Transactions of AACE International CSC 14*, 2004, 1-7.
7. See Jim W. Short, Using Schedule Variance as the Only Measure of Schedule Performance, *Cost Engineering*, Vol 35, No 10, Oct 1993, 35. Also see Walter H. Lipke, "Schedule is Different," *The Measurable News*, Summer 2003, 31-34.
8. Seasoned practitioners of EVM are increasingly realizing that EVM is considerably more useful as a tool for measuring and managing cost performance than it is for schedule performance. Indeed, the earned value concept was developed to get appropriate data for cost assessment. The dollarized schedule assessment is a byproduct fraught with difficulties. In this sense, EVM better serves project managers as a *financial management* tool rather than a cost-schedule-scope *project management* tool.

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Air Force Deployments: Estimating the Requirement

Introduction

Flying combat aircraft out of deployed locations frequently requires deploying thousands of people and thousands of tons of equipment. Determining how much and what kind of each is not easy. Nevertheless, deploying the right amount and types of equipment and people is very important, both during the execution of contingency operations and for planning purposes. During operations, not having enough resources causes risk of not being able to perform the mission. Taking too much risk delays operations, because of unnecessarily tying up lift, or impairs operations elsewhere by unnecessarily tying up resources. During planning, misestimating the resources needed for deployments may lead to a force structure of the wrong size or balance to meet future national security needs.

Whether done for executing a contingency operation or for planning purposes, deployment resource requirements are principally expressed in the form of unit type codes (UTCs). UTCs are sets of equipment and manpower resources needed to perform a specified capability. They vary considerably in size, and the requirements for a deployment to a single base can involve over a hundred UTCs. Various approaches have been used to estimate which UTCs are needed for deployments.

Force Deployment Requirements

The direct way is to assemble an ad hoc group of subject matter experts for all relevant functional areas and have them assess their resource needs given relevant operational details of the contingency. We call this the ad hoc approach to deployment planning. This approach generally begins with a site survey and input information from operational planners giving details of aircraft to be bedded down,

Air Force Deployments: Estimating the Requirement

Both of the approaches for estimating deployment requirements have benefits and shortcomings.

sortie rates, and other relevant factors. Requirements for each functional area are estimated by experts in that area. For example, given the size and numbers of aircraft expected at a base, civil engineers can estimate the water flow needed to meet fire-fighting needs. From this estimate, they determine how many and what types of trucks to deploy. Given the trucks, they in turn estimate the manning and managerial staffing. Other functional areas go through similar, often more complicated, procedures to estimate their resources. For many functional areas, however, the work does not stop at this point because the resource requirements in one area may impact another. For example, civil engineers planning for base support needs—such as number of billets and water and power requirements—need to know how many personnel are expected at the site. This number is determined by the sum of all the other functional areas' requirements. This interdependency forces some communication among the functional area experts, or iteration of estimates, or both. The process necessarily engages numerous personnel and consumes considerable time.

A second way is to determine, in advance of deployments, what is expected to be needed for a nominal deployment location. Such an effort has been recently pursued in the form of force modules. Force modules are sets of UTCs for supporting operations at a nominal location. Within the Air Force, the current implementation of force modules has been developed to estimate the resources needed to operate out of an austere deployed location. Five force modules have been developed.

- Open the base
- Establish the base
- Operate the base
- Provide command and control
- Generate the mission.

These modules represent an integrated capability that crosses many functional areas. The modules not only list UTCs, but also specify the order in which they need to arrive. The task of creating these force modules and testing their deployment at the Eagle Flag exercise has caused UTC contents and sizes to be adjusted for modularity.

Force modules can be viewed as a special case of the ad hoc approach to planning. Groups of subject matter experts have gone through the same process of building a UTC list as in the case for real deployments, except in the case of force modules, the target location is a generic, nominal bare base. Some of the assumptions made in the development of force modules are as follows:

- The base has a water source that can be made potable within 10 days.
- The base has limited fuel storage capability, but fuel is available from the host nation.

- General purpose vehicles can be obtained from the host nation.
- The base has a low to medium threat exposure.[1]

Having studied in advance the needs of a nominal deployed location and made a list of the required UTCs clearly saves time and effort when executing contingencies.

Both of these approaches to estimating deployment requirements have benefits and shortcomings. To see these more clearly, consider the Air Force expeditionary activities of the past few years. To support these contingencies, the Air Force has deployed to dozens of locations, nearly all of them unique in their support requirements. Total numbers of Air Force aircraft at these sites ranged from fewer than ten to more than a hundred. Different airframes have been collocated more often than not. In over half of the locations, aircraft from other Services or coalition partners have shared the base with the Air Force. Additionally, the existing infrastructure at these locations varied widely. A few are truly bare bases, whereas more commonly, the airfield has some kind of usable infrastructure that reduces the resources the Air Force needs to deploy, such as an international airport or coalition partner military airbase. Locations with usable infrastructure also vary considerably, both in the nature of the infrastructure and in how much is made available to deploying forces. Locations of recent deployments indicate that not only is there no typical base in the sense of infrastructure and numbers and types of aircraft, there are scarcely two that are alike.

How well do the ad hoc and force-module approaches handle the vicissitudes of these demands on expeditionary planning? Suppose, for the purpose of sizing the future force, the Air Force needed to estimate the deployment requirements for activities resembling recent contingencies. The ad hoc approach is capable of making good estimates of the UTCs needed to support operations at each of the locations. This accuracy, however, comes at a high cost in time, money, and manpower. Assembling these UTC lists can take teams of experts weeks or months. The costs can be prohibitive, especially if the number of sites to be investigated is numerous, or the number of scenarios to be examined are many.

Force modules economize on the time, money, and manpower of assessing requirements by having standardized these in advance. This economy was indeed one of the main motivations for their creation. Their weakness is that they do so for a generic base, yet no characteristic generic deployed location has emerged from recent deployments. The bases of interest in planning may depart significantly from the one envisioned in the development of the force modules, including such sites as international airports. Without tailoring, force modules fail to accurately capture the nuances of deployment requirements involving a range of base types and mixes of aircraft. These differences will reduce the economies of effort that the force modules would provide had they been able to account for the enormous range in types of Air Force deployed operations. Further, when used to size and shape the

Without tailoring, force modules fail to accurately capture the nuances of deployment requirements involving a range of base types and mixes of aircraft. These differences will reduce the economies of effort that the force modules would provide had they been able to account for the enormous range in types of Air Force deployed operations.

future force, they may not generate the best mix of capabilities to meet national security objectives given a constrained budget.

Here, we introduce a third way to estimate deployment requirements. The proposed method combines the speed at which planning can be done using force modules, with the accuracy of the ad hoc approach. This method extends the concept of force modules from a list of UTCs that support nominal operations out of a generic base to an algorithm that generates a list of UTCs needed at a base that has specified infrastructure and supports specified aircraft and mission. The emphasis is on assembling the *rules* for selecting UTCs rather than assembling *lists* of UTCs. We call this methodology a *parameterized rules-based* approach to calculating deployment requirements. A prototype algorithm using a parameterized rules-based approach for estimating deployment requirements was recently developed by RAND, and is called the Strategic Tool for the Analysis of Required Transportation (START).[2]

The proposed method combines the speed at which planning can be done using force modules, with the accuracy of the ad hoc approach. This method extends the concept of force modules from a list of UTCs that support nominal operations out of a generic base to an algorithm that generates a list of UTCs needed at a base that has specified infrastructure and supports specified aircraft and mission.

A Prototype: The RAND START Algorithm

A parameterized rules-based approach for estimating deployment requirements rests on the principle that expeditionary needs can be calculated accurately enough for planning purposes given a small set of driving factors. Consultations with subject matter experts in a range of support areas confirm this supposition[3]. Many functional areas exercise such rules implicitly during planning, such as the fire-fighting example given above. Most support needs can be estimated from the following.

- The number, type, and sortie rates of the aircraft at the location, and whether they are bedded down at the site, or use it as an enroute base
- The level of risk that the site has from both conventional and nonconventional attack
- A limited number of attributes of the existing infrastructure at the base, such as whether the base has a hydrant fueling system available to the deploying forces, if any billeting is available, and so forth

With these few driving factors and a set of rules, UTC lists can be estimated for most functional areas[4].

We assembled rules for UTC deployment by consulting a number of senior noncommissioned officers and logistics readiness officers. For purposes of demonstrating the concept, the following functional areas were covered: deployed communications, bare-base support, civil engineering (engineering craftsmen, fire protection, explosive ordnance disposal, and readiness), medical, force protection, fuels support, aviation and maintenance, and aerial port operations. The rules were vetted by calculating the needs for a variety of deployments and having these examined by subject matter experts not involved in the consultations used to establish the rules. Generally this meant conferring with experts from one major

command to derive the rules, and consulting experts from another major command to vet the results. The method is similar to what is done in assembling UTC lists by the ad hoc method, or making the UTC lists that constitute force modules, except that what is being assembled is rules rather than UTCs.

The resulting rules were incorporated into Visual BASIC for Applications code hosted in an Excel spreadsheet. The Excel spreadsheet contains a list of available UTCs directly imported from the manpower and force packaging (MEFPAK) database. The user specifies operational details at approximately the level of an air order of battle. Inputs are in the form of checklists that specify the following parameters: which aircraft are bedded down at the location (or use it as an enroute location), how many of each type, their sortie rate, and mission. Some high-level aspects of the available base infrastructure can be selected, such as whether a fuels hydrant system is available, or how much billeting may be available. The user also indicates whether the threat to the base is high, medium, or low for both conventional and nonconventional attack. Finally, a working maximum on ground (MOG) can be specified in order to estimate aerial port equipment and manpower. From these inputs, planning factors are used to calculate base population[5]. The algorithm then takes these parameterized inputs and uses the rules to determine which UTCs are needed and how many. The algorithm searches the MEFPAK for these UTCs and collects the movement data that is compiled in the MEFPAK. The final output is a list of UTCs and their associated movement characteristics[6].

A parameterized rules-based approach for estimating deployment requirements rests on the principle that expeditionary needs can be calculated accurately enough for planning purposes given a small set of driving factors.

Illustrative Applications

The most straightforward illustration is calculating the requirements for a single base hosting a mix of aircraft. Figure 1 shows the requirements for a deployed location with 18 F-16CGs flying 1.5 sorties per day, and 8 C-130s, each flying one sortie per day out of a bare base with a MOG of 2. The threat levels for both conventional and nonconventional attack are taken to be low. This calculation takes a few seconds using the START program. The figure summarizes the requirement in terms of weight; for all functional areas calculated, the sum is 4,775 short tons. These results not only give a planner an excellent starting point for assembling an executable UTC list, but also provide a first-order estimate of the movement requirements. A user can adjust parameters such as the numbers of aircraft, their sortie rates, and so forth in order to examine the impact on the required UTC list. The power of the method is that the UTC list is not static, but can be derived from variations in these input parameters.

Now consider the issue of force lay down as an implicit parameter. For example, what is the difference in the support requirements of the following alternative for the lay down of 3 squadrons of F-16CJs flying 1.5 sorties per day: (1) all three collocated at one bare base; (2) two placed in one bare base and one in a second bare base; or (3) each squadron deployed to its own bare base. Figure 2 shows the results, aggregating all equipment resources in terms of weight. To emphasize the

Air Force Deployments: Estimating the Requirement

Caution should be exercised in extracting rules from historical deployments. We did not use historical data in assembling the rules in the prototype START program. Aside from the limitations of knowing what was not requested during a contingency (because it was already available), and the general reality that operational needs change nearly continuously with time, it is difficult to separate needs from wants.

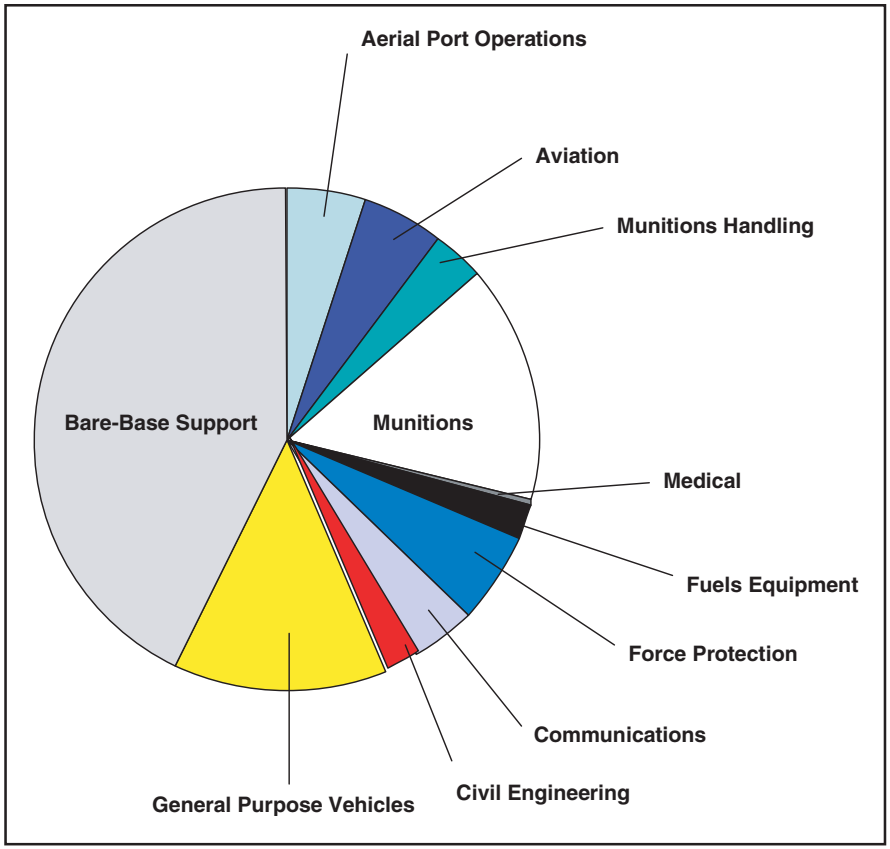

Figure 1. Summary of Support Requirements for a Deployment of a Squadron of F-16CJs and a Squadron of C-130s at One Location

resources that are likely to be deployed, the figure excludes general purpose vehicles. Placing the same numbers of aircraft flying the same mission at three bases rather than one increases the total support materiel by nearly 70 percent. This figure may be an underestimate of the increase, as it does not take into account the likely reduction in personnel needs that the economies of scale of a single base provides. The ability to perform tailored calculations like these can be a useful guide during both deliberate and crisis-action planning.

Finally, note that the algorithm can be used in two directions. A scenario can be created, and the deployment requirements calculated to meet those operational needs. The above calculations are examples of this direction, and this is useful in obvious ways for crisis-action planning, and planning for force sizing. Alternatively, a capability could be specified, such as the ability to deploy a set of aircraft to a

number of sites of certain types. The required resources could then be compared with those currently authorized or available. This direction provides a nuanced way to express Air Force expeditionary capabilities, such as how many bases of a certain type can be supplied by an aerospace expeditionary force (AEF).

Implementing a Parameterized Rules-Based Approach to Deployment Planning

The program we have described is a prototype, concept demonstrator. Additional work will need to be done to make this approach operational. Much of the knowledge needed to implement a parameterized rules-based approach to estimating deployment requirements already exists. A knowledge base of rules for deployments has been developed by most functional areas, and if not yet formalized, exists *virtually* in the subject matter experts.[7]

Areas that have already developed algorithms to assist in estimating deployment, such as fuels support, can furnish such rules without further effort. For most areas, the rules need to be assembled. These could be assembled by a similar effort as was made in creating the force modules.

Caution should be exercised in extracting rules from historical deployments. We did not use historical data in assembling the rules in the prototype START program. Aside from the limitations of knowing what was not requested during a contingency (because it was already available), and the general reality that operational needs change nearly continuously with time, it is difficult to separate needs from wants. Materiel and manpower may be requested during an operation not just to cover the operational needs of the time, but also to mitigate risk in case of an unplanned surge in operations. These needs can be difficult to separate.

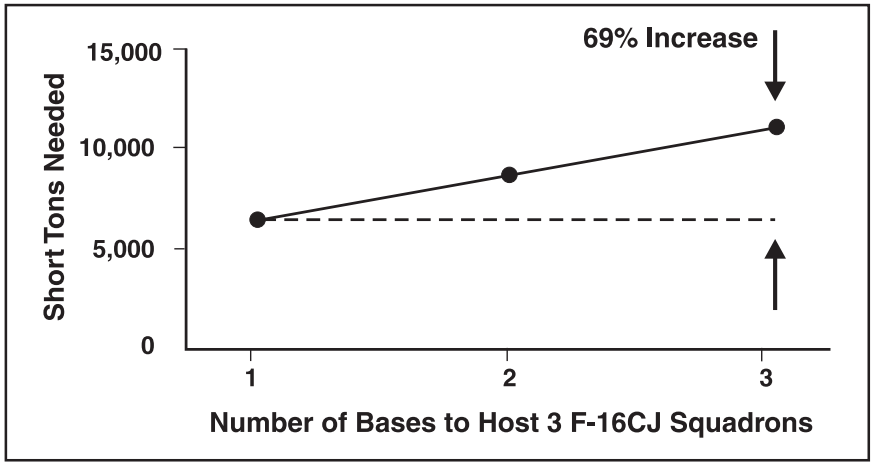

Figure 2. Plot Showing the Increase in Support Needs if 54 F-16CJs are Based at One, Two, or Three Bare Bases

Air Force Deployments: Estimating the Requirement

Once compiled, rules need only be maintained during the routine management of UTCs. As part of the introduction of new UTCs, the pilot unit could be responsible for developing rules for their deployment, just as they now are responsible for estimating movement characteristics. A secondary benefit of this process may be that it impacts the development of UTCs in the same constructive way that force modules have. A parameterized rules-based approach may reveal aspects in which the sizing and constitution of UTCs might be improved to meet expeditionary needs. For example, in some areas, parameterization and rules collection might reveal value in establishing separate UTCs to supply a given capability to a bare base versus an international airport.

We hope this prototype effort will lead to the next step in the evolution of the force module concept, one that moves from UTC lists to sets of rules for deployment. Doing so should further advance the expeditionary mission of the Air Force.

Notes

1. Lt Col Raymone Mijares, Presenting the AEF-AETF Force Modules, 2005.
2. Don Snyder and Patrick Mills, *A Methodology for Determining Air Force Deployment Requirements*, RAND MG-176-AF, 2004. The emphasis on transportation in the name START is because the algorithm was initially written as a component in an analysis of minimizing lift costs for deployments.
3. Don Snyder and Patrick Mills.
4 Other factors can play a role. For example, base layout and topography may influence the needs for vehicles and place greater demands on security forces. If topography impedes line-of-sight communications at the base, additional communications equipment may also be needed. These are secondary factors, and results can be tailored to accommodate these factors when they play a significant role.
5. In the START program, these planning factors for base population are used directly. Further refinement would use these estimates as *seeds* to calculate all manpower needs, then use the sum of the manpower needs as a second estimate of base population. The calculation would then be iterated until convergence.
6. No time-phasing or sourcing of the UTCs is currently done. Time-phasing could be introduced as a further refinement, and the outputs could easily be used as the inputs to an algorithm that does sourcing.
7. Lionel A. Galway, Mahyar A. Amouzegar, Richard J. Hillestad, and Don Snyder, *Reconfiguring Footprint to Speed Expeditionary Aerospace Forces Deployment*, RAND MR-1625-AF, 2002; Lionel A. Galway, Mahyar A. Amouzegar, Don Snyder, Richard J. Hillestad (2002) "Footprint Configuration: An Essential Element for Agile Combat Support in the EAF," *Air Force Journal of Logistics*, Vol XXVI, No 4, 20-26, 43; Don Snyder and Patrick Mills, *A Methodology for Determining Air Force Deployment Requirements*, RAND MG-176-AF, 2004.

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Combat Support: Overseas Basing Options

Introduction

The global geopolitical divide that once defined US military policy faded away as communist governments in Eastern Europe collapsed and the Soviet Union disintegrated in the late 1980s and early 1990s. It was replaced by a security environment characterized both by a range of regional security threats and by a persistent global insurgency and counterinsurgency. The ability of US forces to provide swift and tailored responses to a multitude of threats across the globe is a crucial component of security in today's complex political environment. The Air Force, as with the other Services, has responded by transforming itself into a more expeditionary force. To realize its goals of global strike and persistent dominance, it is vital that the Air Force support the warfighter seamlessly and efficiently in all phases of deployment, employment, and redeployment. One of the major pillars for achieving these objectives is a global combat support basing architecture.

This article focuses on an analytic framework for evaluating options for overseas combat support basing or forward support locations (FSL). The presentation of this framework is important because it addresses how to assess these options in terms of the relevant programming costs while considering a novel approach to scenario planning. This formulation minimizes the costs of facility operation, construction, and transportation associated with meeting the training and deterrent exercises needed to demonstrate US global power projection capability to deter aggression, while maintaining the necessary storage capacity and system throughput to engage in major combat operations.

This framework is based on the notion that US interests are not only global but dynamic as well, particularly when the United States is confronted with emerging anti-access and area denial threats. Consequently, the Air Force must be ready to deploy forces quickly across a wide range of potential scenarios.

Combat Support: Overseas Basing Options

RAND has developed a new framework that integrates the traditional threat-based assessments concept with capability-based planning. This framework relies on a sequenced, potentially simultaneous set of deployment scenarios, which was given the term multiperiod-multiscenario concept.

Development of a Multiperiod, Multiscenario Combat Support Planning Methodology

In recent years, the focus of contingency planners was on individual, deliberate, threat-based deployments. This led to supporting the warfighter by developing *optimal* combat support networks which were designed to counter known threats. An unfortunate characteristic of this type of designed network is that it often performs poorly if the set of demands, such as locations and quantities, differs from the plan. The new planning environment, with its broad and unclear set of potential adversaries, calls for robust and efficient combat support networks that meet operational requirements at reasonable costs over a wide range of contingencies.

The Air Force's new role in this environment will inevitably include a commitment to multiple, overlapping engagements in diverse geographical areas with varying degrees of operational intensity. Some of these engagements, such as drug interdictions, will occur multiple times over a short time horizon. To capture the nuances of the multifaceted, continuous deterrent environment, temporal and spatial elements with other parameters, such as combat support capability and costs must be integrated. These parameters are captured in a new planning methodology in which several likely deployment scenarios, from small-scale humanitarian operations to major regional conflicts, are considered. For any given scenario, decisions should be made regarding its likelihood of occurrence over time, its interrelationship with other scenarios, and its finality.

RAND has developed a new framework that integrates the traditional threat-based assessments concept with capability-based planning. This framework relies on a sequenced, potentially simultaneous set of deployment scenarios, which was given the term *multiperiod-multiscenario (MPMS)* concept. This methodology is a major departure from the current war planning mindset. Previously, whether planning for nuclear warfare against the Soviet Union or for large-scale conventional war in the Near East, US analysts were planning for one large conflict that would occur only once and that would change the defense environment so greatly that plans for outyears following this conflict would no longer be valid.

The Geopolitical Environment

One of the United States' major defense policy goals is to deter threats and coercion against US interests anywhere in the world. This multifaceted approach requires forces and capabilities that discourage aggression or any form of coercion by placing emphasis on peacetime forward deterrence in critical areas of the world. In addition, US forces must maintain the capability to support multiple conflicts if deterrence fails. [1] Air Force core competencies, such as agile combat support, global attack, and rapid global mobility, reflect these changes in the global threat environment. *Global attack capability* is defined as "the ability to engage adversary targets anywhere, [and] anytime." *Rapid global mobility* is defined as "the ability to rapidly position forces anywhere in the world." [2]

The Air Force can rapidly airlift forces anywhere in the world if those forces are sufficiently small, and if the airlift capacity is not consumed by other requirements elsewhere. However, the United States' strategic policy goals and the reality of today's security environment require a capability that can project a continuum of power both swiftly and globally. Doing so requires a combat support system that has both the agility and the adaptability to support a broad range of potential engagements anywhere in the world.

US Operations and Exercises Since 1990

It has been more than a decade since the end of the Cold War, and in that period US forces have been involved in numerous operations and conflicts. Although the United States does not respond to every crisis in the world, the regions of the world in which it has conducted operations reflect the strategic interests of the United States and its allies. Many of the deployments have occurred in regions where the United States has either a permanent support infrastructure, such as Europe, or a long-standing presence, such as the Near East. However, a large number of recent deployments have required US forces to enter new locations that had neither existing US infrastructure nor a historical US presence. Factoring in the relative paucity of these locations' organic logistics infrastructure, these operations and exercises have frequently required deployments to bare bases, with the associated heavy use of combat support assets. The remainder of this section outlines several potential military and nonmilitary operations in the Near East, the Asia-Pacific, Central Asia, South America, Europe, and Northern and Sub-Saharan Africa. The type and the location of potential operations were selected to reflect both historical US involvement and potential locations where future conflicts might intersect with US interests. We were also mindful of selecting a set of operations that would place varying stresses on the combat support system so we could evaluate a wide range of demands on the combat support requirements.

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Near East

Despite the demise of the Baathist regime in Iraq, the US military will continue to be involved in Iraq for the foreseeable future. Moreover, most nations in that region have authoritarian governments.[3] There is a potential for instability in many of these governments, which may not be able to cope with growth in popular unrest. The potential growth of fundamentalism in many Islamic countries may also contribute to further volatility in this region. Although Iran may eventually become friendlier with the United States, its current system of government, with a powerful nonelected head of state, has severely hampered any movement toward normalization of relationships. Crises such as a regime change in Saudi Arabia would further change the security environment in the Persian Gulf and may consequently increase the importance of Iran's role in the region.[4] A destabilized Saudi Arabia and a potentially prolonged interruption of the flow of oil would have severe consequences for the United States and the global economy.[5] Currently, the most immediate threats may

Combat Support: Overseas Basing Options

be the proliferation of weapons of mass destruction and the increase in insurgency movements.

In our analysis we use different types of Southwest Asia (SWA) scenarios to simulate different-sized regional conflicts and to measure the combat support capabilities of alternative FSLs. We also give attention to Eastern Africa, with the Horn of Africa playing an important strategic role.

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Asia-Pacific

Over the past 50 years in the Asia-Pacific region, the United States has focused on the security of South Korea and has established support plans for containing North Korea. Although the United States may not be challenged by a *near-peer* for the near future, the potential exists for regional powers to develop capabilities to threaten US interests. Asia is also a region where there could be large-scale challenges to the US military. China, in particular, may emerge as a more powerful maritime force in the future, challenging the US Navy and Air Force dominance in the Pacific. Although China may not match the advanced military power of the United States, it could play an *asymmetric game* in the region by taking advantage of its vast coastline, as well as the large geographic extent of its rear base that reaches all the way to Central Asia.[6] China, in essence, could occupy the same role in the Pacific in this century that the Soviet Union played in Europe in the latter half of the 20th century. Therefore, *near-peer* scenarios, such as Taiwan-China or China-Russia, can be used to assess the effect of potential FSLs in these very stressing scenarios.

The sea-lanes of the South China Sea and the waters surrounding Indonesia are transited by nearly half of the world's merchant marine capacity. These areas are also critical to the movement of US forces from the Pacific to the Indian Ocean and beyond. Although the end of the Cold War has reduced the clear and immediate global military threat, the potential for both conventional and nonconventional threats still exists. One of the growing concerns is the threat of piracy and its connection to terrorism. Another issue is the overlapping claims to the South China Sea by China, Taiwan, and several Southeast Asian countries all laying claims to some or all of the Spratly Islands.[7] The distances in this region are vast, and US basing and enroute support infrastructure are not as rich as in other important regions. Other potential scenarios in this region include counterterrorism activities in Indonesia or the Philippines and counterinsurgency operations in the Philippines.

Central Asia

The support of some Central Asian countries in Operation Enduring Freedom (OEF), the ongoing US military presence in Afghanistan, and the rich oil reserves of the Caspian Sea region—combined with potential conflicts in the Caucasus and Central Asia—have brought this region to the attention of many policymakers. However, the poor infrastructure of the Central Asian region provides a test to any combat support capability. Moreover, the trepidation of some North Atlantic Treaty

Organization (NATO) allies to project force into the region because of its proximity to Russia could put most of the burden on the United States.[8]

Some Central Asian countries may be able to play a role in supporting the Air Force's continued efforts in Afghanistan or potentially in an Indian-Pakistani conflict. Furthermore, we are interested in measuring the effectiveness of our global storage and maintenance system in supporting the US response to a potential conflict in this region. For example, the tension between the ethnic Kazakh and Russian populations of Kazakhstan could hypothetically trigger a civil war that would lead to the secession of the northern provinces of Kazakhstan or even Russian occupation of part or all of the country.

South America and Caribbean

The United States' continued efforts in antidrug activities in South America is likely to be the main focus for the military in this region.[9] Nevertheless, economic and political upheavals could require differing military roles for US forces in the future. In this region of the world, planning concentrates on small-scale operations that would mostly involve special operations force.

Europe

The United States has strong historical ties with Europe, with dozens of US bases located across the continent. In the near term, it is hard to imagine any major conflicts in Europe such as the ones in the former Yugoslavian states that culminated with Operation Allied Force. Nevertheless, we will include a variation of a Balkan scenario to test United States Air Forces in Europe combat support capabilities. In addition, we assume a continued European role as a support command, as in OEF and Operation Iraqi Freedom.

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Africa

Northern and Sub-Saharan Africa continue to be plagued with civil wars, ethnic or clan-based conflict, and severe economic disasters. The 2003 civil war in Liberia led to the deployment of Nigerian peacekeepers with a small US force in the country.[10] In 2002, with the help of Britain and a large United Nations peacekeeping mission, the West African state of Sierra Leone emerged from a decade of civil war. More than 17,000 foreign troops disarmed tens of thousands of rebels and militia fighters.[11] The Gulf of Guinea in West Africa, particularly Nigeria, has become a strategic interest of the United States because of an increased oil export to the world market.

Recent developments in Northern Africa have been encouraging, with Libya pledging to abandon its pursuit of nuclear weapons. However, the continued threat of insurgencies in Algeria and the Western Sahara may require future US involvement in Northern Africa. The countries of this region continue to be sources of Islamic fundamentalist groups, providing pools of recruits and staging areas for terrorist acts, most notably the Casablanca bombing of May 2003, and possibly the subway attack in Spain on March 11, 2004. Across Africa, political instability and high

levels of violence may continue to persist. The potential for extraction of large volumes of oil from African nations may add to their geopolitical importance. In this region of the world, we concentrate our scenarios on humanitarian support requiring a small-scale aerospace force presentation.

The Tenets of Deployment Scenarios

The primary approach attempts to minimize the overall system cost while meeting operational requirements. The other approach focuses on maximizing the support capability (for example, reducing the time to initial operating capability).

In keeping with the new security paradigm and the concept of MPMS, we constructed a deployment framework using the following tenets.

- Although it is impossible to select combat support bases without specific operational deployments, the selection process should not be slaved to a particular deployment. For that reason, we do not seek to optimize the system for a handful of deployments alone.
- Combat support requirements should be dynamic and deployment scenarios should cast a wide geographical net in order to stress the combat support and transportation requirements.
- Deployments should be sequenced in time and space in order to evaluate physical reach and test long-term effects of location and allocation of assets.
- To hedge against the uncertainty of the future security environment, multiple series of possible scenarios should be developed to test the robustness of the overseas combat support bases.

Analysis Approach

To evaluate and select alternative forward-basing options, we developed an analytic framework that uses an optimization model to assess the cost and capability of various portfolios of overseas combat support basing or FSLs for meeting a wide variety of global force projections.

We have taken two complementary approaches in developing the optimization model. The primary approach attempts to minimize the overall system cost while meeting operational requirements. The other approach focuses on maximizing the support capability (for example, reducing the time to initial operating capability [IOC]). Examining the costs of alternative support basing options, for a constant level of performance against a variety of deployments, is an important process in the development of suitable programming and budgeting plans. In this approach, we are careful to ensure that adequate capacity is maintained to meet requirements as specified in the defense planning scenarios.

Our analyses show the costs and deployment timelines for various FSL options under different degrees of stress on combat support while taking into account infrastructure richness, basing characteristics, deployment distances, strategic warning, transportation constraints, dynamic requirements, and reconstitution conditions. We developed several sets of deployment scenarios using the MPMS concept, with each including training exercises, deterrent missions, and major

combat operations (MCO). These so-called *streams of reality* allow our model to measure the effect of timing, location, and intensity of operational requirements on combat support—and vice versa. We develop several of these streams (or *timelines*) to account for the inherent uncertainties in future planning associated with each timeline.

After we determined the desired requirements in terms of combat support resources, our optimization model, the *RAND Overseas Basing Optimization Tool*, selects a set of locations that would minimize the costs of supporting these various deterrence and training exercises while maintaining the capability to support major regional conflicts should deterrence fail. This tool essentially allows for the analysis of various *what-if* questions and assesses the solution set in terms of resource costs for differing levels of combat support capability.

Our analytic approach has several steps, (Figure 1) as seen below.

- We first select a diverse set of deployment scenarios that would stress the combat support system. These deployments include small-scale humanitarian operations, continuous force presentation to deter aggression, and major combat operations.
- The deployments and the force options drive the requirements for combat support, such as base operating support equipment, vehicles, and munitions.
- These requirements, the set of potential FSLs and forward operating locations (FOL), and the transportation options, such as allowing sealift or not, serve as the inputs to the optimization model.
- The optimization model selects the FSL locations that minimize the FSL facility operating and transportation costs associated with planned operations, training missions, and deterrent exercises that are scheduled to take place over an extended time horizon, satisfying time-phased demands for combat support commodities at FOLs. Major combat operations are included in this analysis to

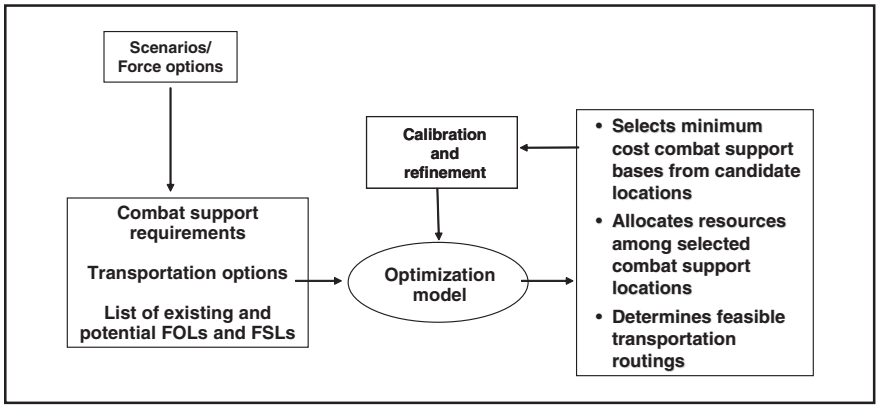

Figure 1. Overview of the Analytic Process for the Optimization Model

These so-called streams of reality allow our model to measure the effect of timing, location, and intensity of operational requirements on combat support—and vice versa. We develop several of these streams (or timelines) to account for the inherent uncertainties in future planning associated with each timeline.

The end result of this analysis is a portfolio containing alternative sets of FSL postures, including allocations of war reserve materiel to the FSLs, which can then be presented to decisionmakers. This portfolio will allow policymakers to assess the merits of various options from a global perspective.

ensure that the resulting network has sufficient capability to allow for such operations should deterrence fail. The transportation costs associated with these operations are not considered in the model because of the different funding mechanisms for the execution of combat operations. The model also optimally allocates the programmed resources and commodities to those FSLs. It computes the type and the number of transportation vehicles required to move the materiel to the FOLs. The result is the creation of a robust transportation and allocation network that connects a set of disjointed FSL and FOL nodes.

- The final step in our approach is to refine and recalibrate the solution set by applying political, geographical, and vulnerability constraints based on current expert judgments concerning the global environment. Since this step is applied post optimally and may make additional iterations necessary, it may require reevalution and reassessment of the parameters and options chosen.

The end result of this analysis is a portfolio containing alternative sets of FSL postures, including allocations of war reserve materiel (WRM) to the FSLs, which can then be presented to decisionmakers. This portfolio will allow policymakers to assess the merits of various options from a global perspective.

Combat Support Factors

Several major constraining and contributing factors affect the capability of FSLs to support the warfighter. Our analytic framework takes each of these parameters into account in its process of selecting an optimal set of combat support locations.

- **Base Access.** This important issue deserves careful consideration and must be addressed before each conflict or operation. However, rather than eliminating some sites a priori because of potential political access problems, we allowed the model to select the most desirable sites based on other factors first. We then *forced* specific sites out of the solution set if we had reason to believe that these sites presented access issues—thereby providing the economic cost of restricting the solution to politically acceptable sites.
- **Forward Support Location Capability and Capacity.** The parking space, the runway length and width, the fueling capability, and the capacity to load and offload equipment are all important factors in selecting an airfield to support an expeditionary operation.[12] Runway length and width are key planning factors and are commonly used as first criteria in assessing whether an airfield can be selected.
- **Airlift and Airfield Throughput Capacity.** Timely delivery of combat support materiel is essential in an expeditionary operation. However, a mere increase in the aircraft fleet size may not improve the deployment timelines. The fleet size must always be determined with respect to the throughput capacity of an airfield.

The maximum-on-ground (MOG) capability, for example, directly contributes to the diminishing return of deployment time as a function of available airlift.

- **Forward Operating Location Distance**. Distance from FSLs to FOLs can impede expeditionary operations. As the number of airlift aircraft increases, the difference in deployment time caused by distance becomes less pronounced. Adding more airlifters to the system will reduce the deployment time, albeit at a diminishing rate, until the deployment time levels off as a result of MOG constraints.
- **Modes of Transportation.** There are several advantages to using sealift or ground transportation in place of, or in addition to, airlift. Allowing for alternative modes of transportation might bring some FSLs into the solution set that otherwise may have been deemed infeasible or too costly. Ships have a higher hauling capacity than do aircraft and can easily carry outsized or super-heavy equipment. In addition, ships do not require overflight rights from any foreign government.
- **Afloat Prepositioning.** We examined the potential for storing combat support resources (munitions and nonmunitions) aboard an Afloat Preposition Fleet (APF). Although afloat prepositioning does offer additional flexibility and reduced vulnerability versus land-based storage, the APF is much more expensive than land-based storage and presents a serious risk with regard to deployment time. Even if a generous advance warning is assumed to allow for steaming toward a scenario's geographic region, it can be difficult to find a port that is capable of handling these large cargo ships. The requirements placed on the port, including preemption of other cargo movement, also restrict the available ports that can be used by an APF.
- **Cost.** The main objective of the model is to reduce the total cost of exercises and deterrent missions while meeting the time-phased operational demand for combat support resources—for those missions as well as for major combat operations. These costs include construction and expansion of facilities and operations and maintenance and transportation for peacetime and training missions. Incorporated in each of these costs is the effect of differences in regional cost-of-living or country cost factors.

Results and Recommendations

We focused on three of the most important combat support resources—basic expeditionary airfield resources (BEAR),[13] munitions, and rolling stock such as trucks. These resources comprise the bulk of many of the consumable and repairable items in the combat support package. In the case of munitions, they pose storage and transport complexities.

From the outset of the study, we attempted to answer two basic questions. First, how capable are the Air Force's current overseas combat support bases of managing the future environment? Second, what are the costs and benefits of using additional or alternative overseas combat support bases for storing heavy combat support materiel?

We focused on three of the most important combat support resources—basic expeditionary airfield resources, munitions, and rolling stock such as trucks. These resources comprise the bulk of many of the consumable and repairable items in the combat support package. In the case of munitions, they pose storage and transport complexities.

Combat Support: Overseas Basing Options

We devised five different streams of reality—or deployment timelines—to represent a wide range of possible future Air Force deployments across the globe.

To answer these questions, we devised five different *streams of reality*—or deployment timelines—to represent a wide range of possible future Air Force deployments across the globe. (Table 1)

The baseline scenario, or the *most likely global deterrent scenario*, places the focus on supporting a number of deployments in the Persian Gulf region, Asian littoral, and North Africa over a time horizon of 6 years, in keeping with the future years defense program (FYDP) convention. Figure 2 represents the size in terms of combat support requirements, and the timing of each deployment for the base scenario. The sizes of recent deployments are given on the y-axis as a reference. Notice that we have *scheduled* the major combat operations in each scenario for execution at the end of the FYDP period. This approach focuses attention on providing resources to support deterrent deployments. It ensures their funding while also placing major combat operations requirements in the planning, programming, budgeting, and execution process.

Selection of Existing Combat Support Bases

We solved the problem of finding the least-cost bases that would satisfy operational requirements using existing forward support locations. For this example it was Ramstein Air Base. The model selected 11 FSLs (Table 2). These locations represent the optimal locations to support the baseline scenario. Although the model was allowed to select from the four existing munitions preposition ships, none was chosen unless infrastructure expansion at the existing land-based FSLs was excluded from the solution. In that case, a single APF ship assigned to the Arabian Sea was used to compensate for the lack of storage space at the land-based FSLs.

	Base Scenario	Stream 1	Stream 2	Stream 3	Stream 4
Year 1	SWA 1	SWA 3	SWA 1	South America 2	Spratleys
	Singapore	South Africa	Horn Africa	Cameroon	Chad
		East Timor		Singapore	
Year 2	Central Asia	Thailand	Central Asia	SWA 3	South America 1
	Thailand	Sierra Leone	Liberia	Thailand	Horn of Africa
				Haiti	
Year 3	Horn of Africa	Spratleys	Balkans	Taiwan	SWA 2
	SWA 2	Haiti	Rwanda	South Africa	Singapore
		Chad			
Year 4	Thailand	Balkans	Singapore	Spratleys	Taiwan
	India	Egypt	Cameroon	Egypt	Haiti
			India		
Year 5	SWA 2	SWA 1	SWA 2	SWA 1	SWA 2
	North Africa	North Africa	Taiwan	Rwanda	East Timor
		Liberia	Sierra Leone	East Timor	
Year 6	Egypt	Central Asia	Spratleys	Central Asia	SWA 1
	Taiwan	India	Chad	North Africa	Rwanda
		Cameroon	Thailand	Singapore	
Year 7+	MCO1	MCO1	MCO1	MCO1	MCO1
	MCO2	MCO2	MCO2	MCO2	MCO2

Table 1. Sequencing of Scenarios by Timeline

Ramstein AB, Germany	Seeb, Oman
Sigonella AB and Camp Darby, Italy	Thumrait, Oman
RAF Mildenhall and Welford, UK	Kadena, Japan
Al Udeid AB, Qatar	Andersen AB, Guam
Sheik Isa, Bahrain	Diego Garcia, UK
Masirah Island, Oman	

Table 2. Optimal Existing FSLs to Support the Baseline Scenario

Ramstein, Germany	Sheik Isa, Bahrain
Sigonella and Camp Darby, Italy	Thumrait, Oman
Mildenhall and Welford, UK	Incirlik, Turkey
Al Udeid AB, Qatar	Clark Field, Philippines
Masirah Island, Oman	Paya Lebar, Singapore
Andersen AB, Guam	U-Tapao, Thailand
Diego Garcia	Balad, Iraq
Kadena, Japan	Seeb, Oman

Table 3. Optimal FSLs from an Expanded Set to Support the Baseline Scenario

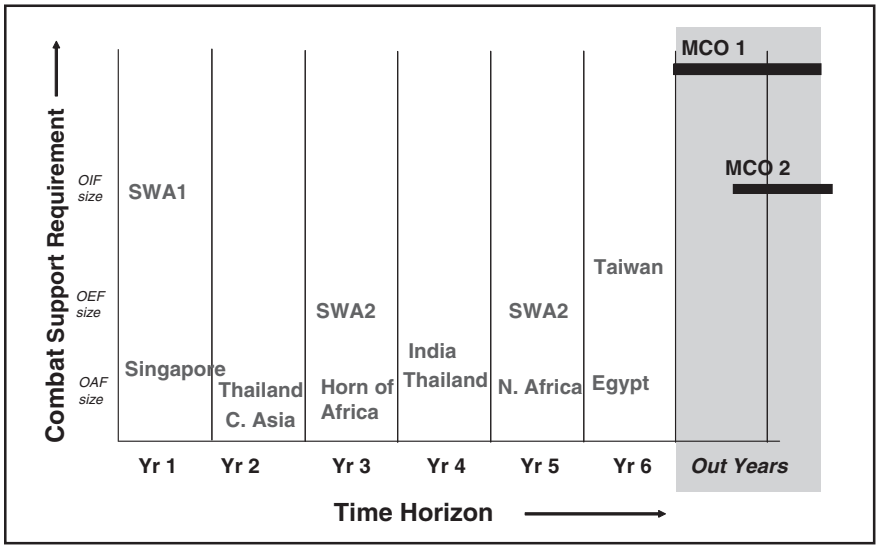

Figure 2. *Most Likely* or Baseline Scenario

The baseline scenario, or the most likely global deterrent scenario, places the focus on supporting a number of deployments in the Persian Gulf region, Asian littoral, and North Africa over a time horizon of 6 years, in keeping with the future years defense program convention.

We assessed the capabilities of the selected FSLs (Table 2) against the remaining four timelines. These FSLs, along with an additional site at Eielson Air Force Base, were able to meet the demand for three of the four additional streams, although with

Combat Support: Overseas Basing Options

increased transportation requirements and costs. However, for Stream 4, the 10-day IOC requirement had to be relaxed to 12 days for the South American deployment, and a single munitions ship, with Guam as its home base, appeared in the solution.

Selection of Additional Combat Support Bases

We generated a list of potential FSL locations around the globe that could support a wide range of deployments. As before, the model selected an optimal list for the baseline scenario—the most likely scenario.

The next step was to evaluate existing and potential FSLs against the baseline scenario and the four alternative streams of reality. We generated a list of potential FSL locations around the globe that could support a wide range of deployments. As before, the model selected an optimal list for the baseline scenario—the *most likely* scenario. The earlier 11 existing sites presented in Table 2 remained in the solution (the model selected them again), along with five new sites in Europe and Asia: Incirlik, Turkey; Clark Field, Philippines; Paya Lebar, Singapore; U-Tapao, Thailand; and Balad, Iraq (Table 3). It should be noted that the list in Table 3 is by no means sacrosanct, and alternative sites may provide the same capability at a similar or marginally greater cost. In particular, Souda Bay, Greece; Akrotiri, Cyprus; Constanta, Romania; or Burgas, Bulgaria may be suitable alternatives to Incirlik, Turkey. In addition, some realignment of existing sites may be more efficient and effective than current sites. For example, the port of Salalla in Oman could be used to meet some requirements met by Seeb or Thumrait with lower cost and less time than the current sites. The new combination of existing and potential FSLs offers about 30 percent savings in total costs by reducing the overall transportation cost to the system.

Figure 3 illustrates the final results from the combination of the baseline scenario and the four other streams of reality. This figure also shows the locations of the

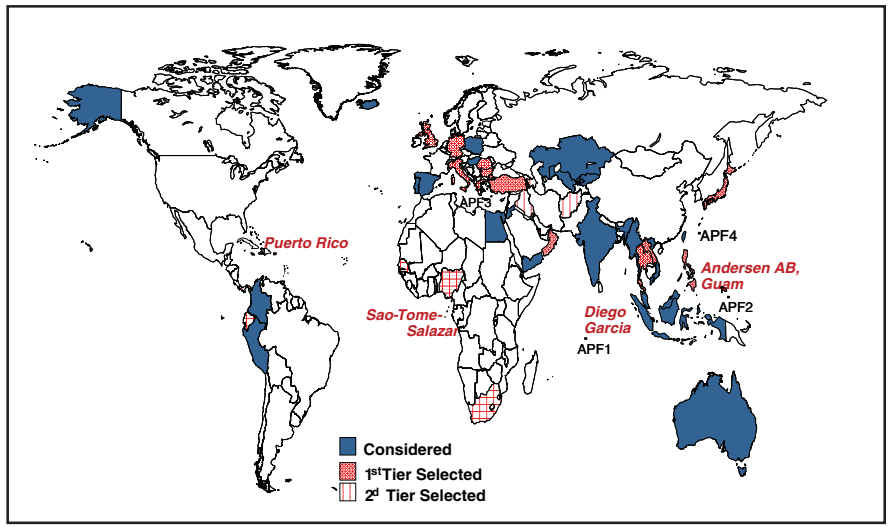

Figure 3. Supporting Global Deterrence Using a Global Set of Overseas Bases

Tier 1	Tier 2
Al Udeid AB, Qatar	Louis Botha, South Africa
Andersen AB, Guam	Bagram, Afghanistan
Diego Garcia	Baku, Azerbaijan
Kadena, Japan	Roosevelt Roads, Puerto Rico
Masirah Island, Oman	Tocumen, Panama
Mildenhall and Welford, UK	Cotipazxi, Ecuador
Ramstein, Germany	Sao Tome/Salazar, Sao Tome
Seeb, Oman	Kaduna, Nigeria[b]
Sheik Isa, Bahrain	Balad, Iraq
Sigonella and Camp Darby, Italy	
Thumrait, Oman	
Clark Field, Philippines	
Incirlik, Turkey	
Paya Lebar, Singapore	
U-Tapao, Thailand	
Souda Bay, Greece[a]	

[a] Alternatives to Souda Bay, Greece, are Akrotiri, Cyprus; Burgas, Bulgaria; or Constanta, Romania.
[b] An alternative to Kaduna, Nigeria, may be Dakar, Senegal.

Table 4. Global Set of Overseas Bases

other candidate sites that were not selected by the model. It and the accompanying Table 4 divide these locations into Tier 1 and Tier 2 categories. We use the label *Tier 2 FSLs* for a set of FSLs that require a more detailed consideration as potential sites. They may also have appeared in the solution as a result of one or two individual deployments, and therefore their role is closely fixed to the nature of those particular deployments. Additionally, all the Tier 2 FSLs, with the exception of Puerto Rico, have uncertain political futures or limited internal capabilities. Iraq, for example, falls in this category, but its location for support of many operations makes it invaluable. However, we emphasize that the focus should not be on a particular latitude and longitude but rather on a particular region. Balad, Iraq, would be suitable if all the issues of security and long-term political amenities were resolved. If the uncertainties continue, then an alternative location in the region with similar capabilities should be considered.

For each stream the expanded set of FSLs offer the same capability at a reduced overall cost to the Air Force.

Figure 4 presents the costs for the base scenario and all four streams. For each stream the expanded set of FSLs offer the same capability at a reduced overall cost to the Air Force. Note especially that the set of existing land-based FSLs could not support Stream 4 requirements and required that the IOC deadline be extended from 10 to 12 days and also required the use of an APF munitions ship. However, when we selected from the expanded set of land-based FSLs, the need for the afloat option disappeared. The advantage of the global basing option is not limited to cost and

Combat Support: Overseas Basing Options

For each stream, the model was able to make better use of trucks and high-speed sealift for the expanded pool of bases, yielding about 50 percent less airlift usage without compromising operational requirements.

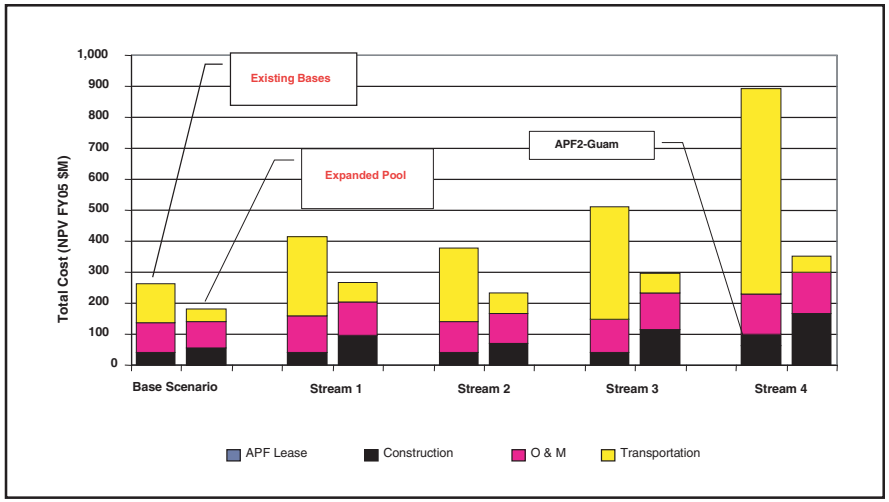

Figure 4. Total Cost of Supporting All Scenarios Using Existing and Expanded Set of FSLs

encompasses a more efficient use of multimodal transportation. For each stream, the model was able to make better use of trucks and high-speed sealift for the expanded pool of bases, yielding about 50 percent less airlift usage without compromising operational requirements.

Recommendations

We make the following recommendations based on our analysis of overseas combat support basing options.

- **Using a global approach to select combat support basing locations is more effective and efficient than allocating resources on a regional basis.** One of the strengths of the analytic framework chosen is the lack of regional command boundaries. We are able to look at all regions of the world simultaneously with operations occurring in various locations at the same time, thereby extracting the most efficient solution without adversely compromising the capability needs of a particular region.
- **Political concerns need to be addressed in any decision about potential overseas basing locations.** For instance, while an APF is much more expensive than alternative land-based storage options and may suffer from increased risk in deployment time, it may be necessary to consider the APF option because it offers more flexibility if access is denied. Additionally, countries like Iraq are continually selected by the model because cost and time are its major driving criteria. However, the uncertainty surrounding the future of Iraq (and similar

countries) should force us to pause and consider alternative sites that may be less desirable mathematically but offer a higher probability of access and stability.

- **Closer attention should be paid to Africa both as a source of instability and as a possible location for combat support bases.** Africa, with its potential as a source of future oil combined with the uncertain future of many of its nation states, requires a great deal of attention from policymakers. Northern and Sub-Saharan Africa continue to be plagued by civil wars, ethnic, or clan-based conflicts, and severe economic disasters. There is an increased likelihood that terrorists may seek haven in the remote areas of Africa because of the continued US military presence in the Middle East and Southwest Asia. Also, the geopolitical importance of the region, with its high levels of oil production, makes it an area of interest to the United States. If deployments to the region increased in the future, the current set of bases would not support those operations. Possible FSL locations in Africa could support operations across the entire southern half of the globe. Although the initial construction costs for these bases would be high, the costs would be quickly offset by the reductions in transportation costs. As an initial phase, we recommend closely evaluating western regions of Africa, with particular attention to Nigeria, Sao Tome/Salazar, and Senegal, along with South Africa.
- **Some Eastern European nations should be considered as serious candidates for future overseas bases.** The potential for continued conflicts in central Asia and the Near East has made many of the countries in the eastern part of Europe very attractive as potential storage locations for WRM. The appeal of this region has been further heightened by the inclusion of some of these countries in the European Union and NATO, combined with the lower cost of living and the relatively large professional labor market. Romania and Bulgaria in Eastern Europe, along with Mediterranean locations such as Greece and Cyprus, form an appealing region that would allow easy access to both the United States Central Command and the United States European Command areas of responsibility. These locations are especially attractive because they allow for multimodal transport options, using Black Sea ports for Romania and Bulgaria, assuming passage through the Bosporus Strait in Turkey to the Mediterranean. Poland and the Czech Republic, although very accommodating to US efforts in the current operations, are located relatively far from the potential deployments that were considered in this report. Also, the Czech Republic is a landlocked state, and while Poland has significant coastline on the Baltic Sea, these ports do not allow for rapid transport to the regions of Air Force interest. In terms of transportation time and cost, Germany can provide a better capability than either Poland or the Czech Republic, because of existing US installations.
- **Southeast Asia offers several robust options for allocation of combat support resources.** The remoteness of Guam and Diego Garcia from most potential conflicts in the region requires the consideration of other locations in the Pacific. The geographical characteristics of the United States Pacific Command put a

Combat Support: Overseas Basing Options

heavy reliance on airlift and possibly fast sealift. Most of the current US bases are located in Japan and the Korean Peninsula with the main purpose of supporting the Korean deliberate plan. To support other possible contingencies, we propose a closer examination of three locations—Thailand, Singapore, and the Philippines. Each of these locations offers a host of options for the Air Force, including storage space, adequate runway facilities, proximity to ports, and strategic location. Darwin, Australia, has many of the desired attributes for an overseas combat support base, but its remoteness to most potential conflicts makes it a comparatively poor choice.

- **Potential future operations in South America may be greatly constrained unless additional infrastructure in the region is obtained.** In our analysis, a large South American scenario obtained from the defense planning scenarios overstressed the system of existing facility locations, preventing the satisfaction of a 10-day IOC deadline, even with the use of APF ships. While the states of South America are relatively stable, the recent difficulties in Ecuador, Bolivia, and Venezuela demonstrate the potential volatility of the region. As with Africa, future US intervention cannot be discounted owing to significant US interests in the region's oil supply. Although the current combat support infrastructure is sufficient for small-scale operations such as drug interdiction, an expanded combat support presence would facilitate larger-scale operations in the region.
- **Multimodal transportation option is the key to rapid logistics response.** RAND has shown in several earlier reports that overreliance on airlift may in fact reduce response capability because of throughput constraints and lack of airlift.[14] A comprehensive mobility plan should include a combination of air, land, and sealift. Judicious use of trucks and high-speed sealift in fact may offer a faster and less expensive way to meet the Air Force's mobility needs.

Notes

1. United States Department of Defense, "Military Transformation: A Strategic Approach," fall 2003.
2. United States Air Force, "Air Force Strategic Plan, Long-Range Planning Guidance, Volume 3," May 2000.
3. The main exception is Israel, which is democratic. It is certainly too early to assess the outcome of Iraq's recent elections.
4. For more information on Iran and its security strategies see the following publications:
   Daniel Byman, Shahram Chubin, Anoushiravan Ehteshami, and Jerrold Green, *Iran's Security Policy in the Post-Revolution Era*, Santa Monica, CA: RAND Corporation, MR-1320-OSD, 2001.
   Shahram Chubin, "Whither Iran? Reform, Domestic Politics and National Security," Adelphi Paper, Issue 342, The International Institute for Strategic Studies, 2002.
5. Richard Sokolsky, Stuart E. Johnson, and F. Stephen Larrabee, *Persian Gulf Security: Improving Allied Military Contributions*, Santa Monica, CA: RAND Corporation, MR-1245-AF, 2000.
6. As a simple illustration of the size of the US and Chinese navies, consider the following: The US Navy's warships have a total "full-load displacement" of about 2.9 million tons, whereas

China's have less than 300,000 tons. The United States deploys 24 aircraft carriers (out of world's 34); China deploys none.

7. Zalmay Khalilzad and Ian Lesser, *Sources of Conflict in the 21st Century*, Santa Monica, CA: RAND Corporation, MR-897-AF, 1999.
8. Richard Sokolsky, Stuart E. Johnson, and F. Stephen Larrabee.
9. At the urging of Peru and Colombia, President Bush may authorize the resumption of antidrug surveillance flights over Colombia. (*The New York Times*, 6 Aug 2003)
10. The role of American troops was confined to assisting with logistics, reflecting the general uneasiness of the Pentagon over making a long-term commitment while US troops were heavily committed in Afghanistan and Iraq (*The New York Times*, 5 Aug 2003)
11. A short description of this action may be found on the BBC News Web site, [Online] Available: http://news.bbc.co.uk/1/hi/world/africa/country_profiles/1061561.stm (last accessed 7 Oct 2005).
12. In our analysis, some of these factors are computed parametrically in order to assess a minimum requirement of a potential field for meeting a certain capability.
13. BEAR provides the required airfield operational capability (such as housekeeping or industrial operations) to open an austere or semi-austere airbase.
14. Mahyar A. Amouzegar,Robert S. Tripp, Ronald G. McGarvey, Edward W. Chan, and C. Robert Roll, Jr, *Supporting Air and Space Expeditionary Forces: Analysis of Combat Support Basing Options*, Santa Monica, CA: RAND Corporation, MG-261-AF, 2004. Alan Vick, David T. Orletsky, Bruce Pirnie, and Seth G. Jones, *The Stryker Brigade Combat Team, Rethinking Strategic Responsiveness and Assessing Deployment Options*, Santa Monica, CA: RAND Corporation, MR-1606-AF, 2002.

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Sense and Respond Combat Support

Introduction

Modern warfare has evolved from conflicts dominated by massed manpower, the so-called *first generation* of modern (post-Westphalian) war, to a warfare that has integrated political, social, economical, and technological issues. A recent National Defense University study maps this evolution from first generation warfare, culminating in the Napoleonic Wars, to second-generation wars dominated by firepower. Third generation war was the new maneuver tactics developed by the Germans in World War II. Unconventional enemy, in terms of insurgencies and counter-insurgencies, dominates the fourth generation.[1] In fourth generation warfare, the nation-states no longer hold a monopoly on weapon systems and may be involved in long conflicts with stateless enemies. Although insurgency is not new (dating back over 2 millennium)[2] the political features of insurgency have become a predominate character of modern insurgents. Advances in information technology also have had a revolutionary impact in these types of warfare.

A constant throughout the history of warfare has been the central role of logistics in the successful prosecution of any conflict. However, the 20th century logistical system lagged behind rapidly changing technology and tremendous efforts were put into the scientific study of logistics. Most of the early supply systems operated on a *push* concept rather than in response to actual needs and changes. It was thought that having an abundance of resources in-theater ensured that combat support (CS) elements would be able to provide everything needed to achieve the desired operational effects. In practice, the presence of *mountains of supplies* did not always ensure warfighters' demands were met. In fact, the backlog of war materiel congested the CS system because of inefficiencies in the transportation system and the prioritization processes. It was evident that a more comprehensive capability was

Sense and Respond Combat Support

needed for matching CS assets to warfighter needs. In the past, prediction and responsiveness have been viewed as competing concepts. However, in this article, we argue that both are necessary and can be integrated within a command and control system to create military sense and respond capabilities.

Military logistics planning grew even more difficult with the collapse of the Soviet Union and the dissolution of the associated threat to United States interests in Europe. The shift in global power exposed the inefficiencies of legacy CS systems that had been hidden under a static and focused, albeit immense, threat. The geopolitical divide that once defined US military policy was replaced by a temporary rise of regional hegemons, which in turn slowly evolved (and continues to evolve) into a geopolitical environment that is defined not only by regional powers, but also by nontraditional security threats. The uncertainty associated with planning for military operations was thus extended to include uncertainty about the *locations* and *purpose* of operations.

The Air Force, in response to the changing military environment, designed and developed a transformational construct called the Air and Space Expeditionary Force (AEF).[3] The implementation of the AEF changed the Air Force's mindset from a threat-based, forward-deployed force designed to fight the Cold War to a primarily continental United States-positioned, rotational, and effects-based force able to rapidly respond to a variety of threats while accommodating a high operations tempo in the face of the uncertainties inherent in today's contingency environment. The AEF prompted a fundamental rethinking and restructuring of logistics. This modern perspective of CS does not merely consider maintenance, supply, and transportation but is expanded to include civil engineering, services (billeting and messing), force protection, basing, and command, control, communications, and computers.

The shift to a more expeditionary force compelled a movement within the Air Force toward a capability called agile combat support (ACS). One of the Air Force's six distinctive capabilities, ACS includes actions taken to create, effectively deploy, and sustain US military power anywhere—at our initiative, speed, and tempo. ACS capabilities include provision for and protection of air and space personnel, assets, and capabilities throughout the full range of military operations.[4] ACS ensures that responsive expeditionary support for right-sized forces used in Joint operations is achievable within resource constraints. ACS began to emerge as a concept in a series of Air Force and RAND publications,[5] which detailed both micro- and macro-level analyses. One of the key conclusions of these studies has been the need for a robust and responsive combat support command and control (CSC2) architecture.

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Combat Support Command and Control: Key to Agile Combat Support and Essential for Sense and Respond Combat Support

Command and control (C2), although often associated with operations, is also a fundamental requirement for effective CS. As warfighting forces become more flexible in operational tasking, the support system must adapt to become equally

flexible. The C2 of modern CS assets must be woven thoroughly with operational events—from planning through deployment, employment, retasking, and reconstitution. Additionally, CS goals and objectives must be increasingly linked directly to operational goals and objectives. The traditional distinction between *operations* and *CS* loses relevance in such an environment. CS activities need to be linked to operational tasking with metrics that have relevance to both warfighter and logistician.

In essence, CSC2 sets a framework for the transformation of traditional logistics support into an ACS capability. CSC2 should provide the capabilities to:

- Develop plans that take operational scenarios and requirements, and couple them with the CS process performance and resource levels allocated to plan execution to project operational capabilities. This translation of CS performance into operational capabilities requires modeling technology and predicting CS performance.
- Establish control parameters for the CS process performance and resource levels that are needed to achieve the required operational capabilities.
- Determine a feasible plan that incorporates CS and operational realities.
- Execute the plan and track performance against calculated control parameters.
- Signal all appropriate echelons and process owners when performance parameters are out of control.
- Facilitate the development of operational or CS get-well plans to get the processes back in control or develop new ones, given the realities of current performances.

CSC2 is not simply an information system. Rather, it sits on top of functional logistics systems and uses information from them to translate CS process performance and resource levels into operational performance metrics. It also uses information from logistics information systems to track the parameters necessary to control performance. It includes the battlespace management process of planning, directing, coordinating, and controlling forces and operations. Command and control involves the integration of the systems, procedures, organizational structures, personnel, equipment, facilities, information, and communications that enable a commander to exercise C2 across the range of military operations.[6] Previous studies built on this definition of C2 to define CS execution, planning, and control to include the functions of planning, directing, coordinating, and controlling CS resources to meet operational objectives.[7]

The objective of this transformed CSC2 architecture is to integrate operational and CS planning in a closed-loop environment, providing feedback on performance and resources.

The objective of this transformed CSC2 architecture is to integrate operational and CS planning in a closed-loop environment, providing feedback on performance and resources. The new CSC2 components significantly improve planning and control processes, including:

- Planning and forecasting (prediction)

- Joint analysis and planning of CS and operations
- Determining feasibility, establishing control parameters

- Controlling
  - Monitoring planned versus actual execution—a feedback loop process allowing for tracking, correction, and replanning when parameters are out of control
- Responsiveness
  - Quick pipelines and the ability to respond quickly to change

A robust CSC2 construct will enable a sense and respond capability that integrates operational and CS planning in a closed-loop environment, providing feedback on performance and resources.

One of the key elements of planning and execution is the concept of an effective feedback loop that specifies how well the system is expected to perform during planning, and contrasts these expectations with observations of the system performance realized during execution. If actual performance deviates significantly from planned performance, the CSC2 system warns the appropriate CS processes that their performance may jeopardize operational objectives. The system must be able to differentiate small discrepancies that do not warrant C2 notification from substantial ones that might compromise future operations. This requires the identification of *tolerance limits* for all parameters, which is heavily dependent on improved prediction capabilities. This feedback loop process identifies when the CS plan and infrastructure need to be reconfigured to meet dynamic operational requirements and notifies the logistics and installations support planners to take action, during both planning and execution.

A robust CSC2 construct will enable a sense and respond capability that integrates operational and CS planning in a closed-loop environment, providing feedback on performance and resources. Figure 1 illustrates this concept in a process template that can be applied through all phases of an operation from readiness, planning, deployment, employment, and sustainment to redeployment and reconstitution.

This comprehensive transformation of CSC2 doctrine and capabilities blends the benefits of continuously updated analytical prediction with the ongoing monitoring of CS systems, which, given a robust transportation capability, enables the rapid response necessary to produce a sense and respond combat support (S&RCS) model appropriate for military operations in the 21st century.

Defining Sense and Respond Combat Support

The emphasis on the ability to *respond* quickly and appropriately through the command and control function to the broader areas constituting CS is how this article differentiates S&RCS from the traditional definition of sense and respond logistics (S&RL). Implementing S&RL concepts and technologies through the CSC2 architecture is the way to achieve an S&RCS capability.

In an often volatile commercial market, the manufacturer and distributor constantly monitor changes in buying patterns and adapt quickly to maintain market share. By employing S&RL, commercial enterprise has been able to reduce

investments in warehouses and stock. Industry now increasingly produces what is desired and required rather than what a planner thinks should be built based on internal production goals. Commercial S&RL, in theory, reduces stock and overhead costs and responds rapidly to change.[8] The key to these improvements is a robust system of information-gathering and analysis or, in military terms, a highly efficient C2 system.

Commercial practices and commercial definitions of S&RL fall short of what is needed to create S&RCS in the Air Force environment. Although there are similarities between some of the issues and constraints of the military and those of a large corporation, the risk of human casualty, the consequences to the international political order, and vastly different military objectives set the Department of Defense (DoD) apart from any corporation of comparable size. The scope of activities included in military CS is also much broader than that of commercial logistics; any reorganizational concept must consider the nuances of military operations. It is interesting to note that firms have designed lean supply chains to be resilient to business disruptions,[9] but it has been shown that resiliency for firms may not translate to resiliency for the entire supply chain and the government provision of pliability and redundancy may be necessary in an era of lean supply chain management.[10] In the military case, the Air Force is the sole user and provider and thus the business notions of resiliency may not be entirely applicable.

Traditionally, ongoing planning and tasking often occur in isolation from those who would subsequently be required to support the levels and rates of tasking. Coordination, if any, occurs after initial planning cycles are completed. Modern, responsive systems demand information-sharing among all partners in the military enterprise. Moreover, tools and technology play a vital role in this enterprise.

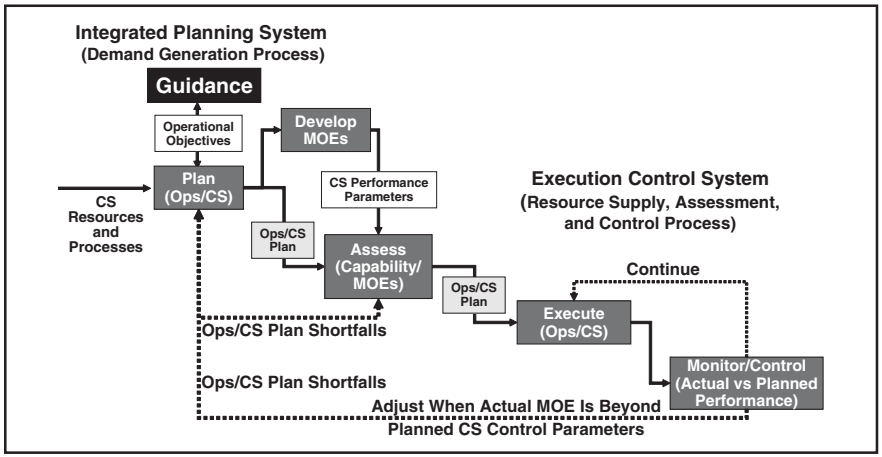

Figure 1. Feedback Loop Process

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A Brief Survey of Sense and Respond Tools and Technology

The DoD Office of Force Transformation (OFT) developed the military sense and respond logistics concept, borrowing heavily from research in the commercial sector (which was in turn indebted to earlier military efforts, such as the observe, orient, decide, and act loop)[11] to describe an adaptive method for maintaining operational availability of units by managing their end-to-end support network. OFT addresses S&RL from a Joint force perspective and as an important component of DoD's focused logistics strategy.

OFT has also identified a number of technologies that are essential in an S&RL system, two of which were highlighted as especially important components: radio frequency identification and intelligent (adaptive) software agents.

OFT considered architectural development planning that includes the development of an information technology S&RL prototype. One of these architectural concepts is the Integrated Enterprise Domain Architecture, which has the objectives of integrating, accommodating, and employing concepts and components of logistics, operations, and intelligence architectures and of their command, control, communications, computers, intelligence, surveillance, and reconnaissance concepts.[12] Presently, Integrated Enterprise Domain Architecture is in a predevelopment stage, but plans are to eventually link it to other architectures or programs, including Joint Staff J4, Joint Forces Command, US Marine Corps, United States Transportation Command, and possibly certain organizations in the Navy and the Army. Among the in-work project linkages is the RAND-Air Force CSC2 Operational Architecture as the Air Force vehicle for coordinating with concepts in S&RL.

Overall, the OFT program for S&RL is in a very early stage, but it has the potential to influence and effect near- to mid-term changes in some current programs using S&RL technologies. OFT suggests that elements of the concept can be employed in an evolutionary development in the very near term and could result in immediate operational gains.[13] OFT has also identified a number of technologies that are essential in an S&RL system, two of which were highlighted as especially important components: radio frequency identification and intelligent (adaptive) software agents.

However, before we discuss these components it is noteworthy to present some of the technical requirements that are essential in supporting sense and respond CS. Although there is great diversity amongst various approaches to sense and respond logistics implementation and its applications, a general theme is best stated by the IBM Sense and Respond Enterprise Team.[14] These criteria are in line with RAND's CSC2 concepts which the Air Force is in the process of implementing.[15] In general, technologies and innovation to support sense and respond (S&R) must have the following:

- The ability to detect, organize, and analyze pertinent information and sense critical business (force) conditions

- The filters for enterprise data to enable stable responses to disturbances in the business or military environment
- The intelligent response agents that analyze global value chain relationships and information and derive the optimal strategy for the best supply chain performance
- Predictive modeling at multiple levels: strategic, tactical, and operational
- Agent coordination mechanisms at multiple levels: strategic, tactical, and operational
- The ability to learn by comparing previously predicted trends with recorded data and information to improve future responses
- A software infrastructure to integrate heterogeneous and collaborative agents implementing critical business policies and making operational decisions

This concept can be contrasted with the OFT perspective. OFT, within its All Views Architecture, lists specific systems architecture components for S&RL, including the following capabilities:[16]

- Passive and active tagging, instruments, and sensors that provide location status, diagnoses, prognoses, and other information relative to operations space entities, especially for conditions and behavior that affect force capabilities management, logistics, and sustainment.
- Intelligent software agents that represent operations space entities, conditions, and behaviors, provide a focus for control of action or behavior, or act as monitors.
- S&RL knowledge bases oriented toward force capabilities management, logistics, and sustainment.
- S&RL reference data, again focused on force capabilities, assets, and resources related to force capabilities management, logistics, and sustainment.
- S&RL rule sets, which govern the operations and organization of S&RL functions, activities, and transactions.
- S&RL cognitive decision support tools uniquely supporting force capabilities management, logistics, and sustainment.
- Unique S&RL processes, applications, portals, and interfaces not provided either by Distributed Adaptive Operations Command and Control or the Network-Centric Operations and Warfare infrastructure.

These are representative of the technologies and innovations that have been identified with military and commercial S&RL initiatives. In the next section, we discuss two important technologies needed to enable an ultimate S&RCS capability: radio frequency identification (RFID) and intelligent (adaptive) software agents.[17]

Radio Frequency Identification. RFID is an automatic identification technology that provides location and status information for items in the CS system. RFID

RFID is an automatic identification technology that provides location and status information for items in the CS system. RFID technologies are fairly mature and have been fielded in both commercial and military arenas.

Sense and Respond Combat Support

Technically, RFID offers a way to identify unique items using radio waves. Typically, a reader communicates with a tag, which holds digital information in a microchip. However, some chipless forms of RFID tags use material to reflect back a portion of the radio waves beamed at them. This technology is of equal interest to military and commercial enterprises.

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There are several examples of real-time information-gathering and distribution. For example, in Iraq, some Marine units had active tags not just on pallets but also on vehicles. RFID readers were set up at a distribution center in Kuwait, at the Iraq-Kuwait border, and at checkpoints along the main arteries in Iraq. When trucks passed the readers, the location of the goods they were carrying was updated in the DoD's intransit visibility network database. This enabled commanders on the ground to see the precise location of the replenishments needed to sustain operations. RFID implementation is limited, but the DoD goal is to minimize human involvement when collecting data on shipments and their movements.

The Application of Agent Technology. The application of agent technology in S&RL research has become pervasive both in military and nonmilitary programs. Agent-based modeling (ABM) allows a more robust simulation of CS operations.[18] Agent-based models are already in wide use within the DoD for force-on-force simulations but have only recently been adapted for military logistics use. The logistics domain is distributed and involves decentralized (autonomous) organizations. These organizations are also

- Intentional entities, with goals, functions, roles, and beliefs, using processes and expertise to achieve their goals
- Reactive, and thus responsive to changes that occur in their environment
- Social, so they interact with other organizations to achieve their goals, where the social interaction is typically complex, such as negotiation, rather than just action requests

The similarity in characteristics between agents and organizations makes agents an appropriate choice for modeling organizations. This also explains agent functionality in carrying out organizational or human processes in S&RL applications. Moreover, robust distributed C2 strategies can also be tested using ABMs.[19] Although some simple supply chain simulations have been done for logistics, almost none have modeled actual organizations with the requisite detail and calibration necessary to compare alternative policies and gain insight.

Although individual automated software agents are already employed commercially for particular tasks, intelligent multi-agent systems are still in early development.[20] Consequently, ABMs have only had a limited effect on practical decisionmaking. Only in recent years have academic researchers explored the use of intelligent agents for supply chain management.[21] Although ABMs are properly understood as multi-agent systems, not all agents or multi-agent systems

are employed for modeling and simulation purposes. Several researchers, including some under DoD contracts, have developed applications of ABMs for supply chain management.[22]

Agents have been used in telecommunications, e-commerce, transportation, electric power networks, and manufacturing processes. Within telecommunications, software agents bear the responsibility for error-checking (such as dropped packets), routing and retransmission, and load-balancing over the network. Web-search robots are agents that traverse Web sites collecting information and cataloging their results. When a customer searches for an item on a Web site, say Amazon.com, at the bottom of the page there is a list of similar products that other customers interested in the item also viewed. Similar agents assemble customized news reports and filter spam from e-mail. Data-mining agents seek trends and patterns in an abundance of information from varying sources and are of particular interest for all-source intelligence analysis.[23]

A World of Initiatives

The following discussion represents recent and current initiatives, both public and private, to develop sense and respond capabilities.

- The Defense Advanced Research Projects Agency (DARPA) has been working on an end-to-end logistics system under the Advanced Logistics Project.[24] Under this project, DARPA developed an advanced agent architecture with applications to logistics. As follow-on to Advanced Logistics Project, DARPA initiated a program called Ultra-Log that attempted to introduce robust, secure, and scalable logistics agents into the architecture. Ultimately, Ultra-Log is seeking valid applications to DoD problems (such as Defense Logistics Institute applications) while adopting commercial open-source models.
- DARPA led another experiment called Coalition Agent eXperiment (CoAX), which was an example of the utility of agent technology for military logistics planning. A multi-agent logistics tool, implemented within CoAX, was developed using agent technology to have agents represent organizations within the logistics domain and model their logistics functions, processes, expertise, and interactions with other organizations. The project generated important lessons for S&RL, identifying two types of issues that need to be overcome for agents to be effectively used for military logistics planning—technological and social (human acceptability). RAND believes the issues are the same for use in executing logistics functions. Under technology, the identified issues include logistics business process modeling, protocols, ontologies, automated information-gathering, and security. We found some of these being addressed in DARPA's work. Under social acceptability, the following were important: trusting agents to do business for you, accountability and the law, humans and agents

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Sense and Respond Combat Support

Without the proper metrics for measuring the agent (and other) technologies used in S&RCS implementation, it is difficult to project where or when CSC2 effectiveness best stands to gain from this technology insertion. This is an important subject to address through information technology prototyping for CSC2 because it should drive information technology investments among S&RL technologies.

working together, efficiency metrics, ease of use, adjustable autonomy, adjustable visibility, and social acceptability versus optimality.

- The Air Force Research Laboratory, Logistics Readiness Branch (AFRL/HEAL) has focused its attention on human factor issues in S&RL, with a concentration on cognitive decision support.[25] AFRL proposes to focus on the human aspects of distributed operations by researching and developing enhanced or novel methodologies and measures to evaluate the effect of collaboration technologies on human performance from an individual, team, and organizational perspective. This group suggests that human performance metrics should be created along with other performance metrics for S&RL functions and activities in the military enterprise, although such considerations are currently not being called for in the requirements.

In addition to the multiple DoD-led initiatives, a number of commercial sector and university initiatives have developed some of the technologies needed to enable an S&RCS capability and presents a number of industrial applications of fielded S&R systems. These included an IBM Sense and Respond Blue program, which was a major influence on the military OFT enterprise definition and emphasized the employment of careful planning as well as intelligence, flexibility, and responsiveness in execution in order to achieve high levels of distributed efficiency.[26] In addition, General Electric Transportation Systems developed and fielded an autonomic logistics capability for its locomotive engine business. This capability is enabled through an onboard computing and communications unit that hosts software applications, continuously monitors locomotive parameters, and provides communications to General Electric's Monitoring and Diagnostics Service Center.[27]

Based on this technology review of both military and commercial activities and initiatives (and a more thorough review detailed in the RAND monograph[28]), we concluded that although current technology has enabled a limited set of sense and respond capabilities, a full implementation of S&RL concepts remains dependent on substantial future technological development. The largest challenge ahead for implementing a broader S&RCS capability is the development of an understanding of the interactions between CS system performance and combat operational metrics. Without the proper metrics for measuring the agent (and other) technologies used in S&RCS implementation, it is difficult to project where or when CSC2 effectiveness best stands to gain from this technology insertion. This is an important subject to address through information technology prototyping for CSC2 because it should drive information technology investments among S&RL technologies.

Air Force Combat Support Command and Control Implementation Effort

The Air Force has taken initial steps to implement the CS command and control operational architecture. Its efforts are designed to help enable AEF operational goals. Implementation actions to date include changes in C2 doctrine, organizations,

processes, and training. Although progress has been steady, the area of information systems and technology requires increasing application of modern capabilities. The emerging modernized logistics information systems emphasize mostly business process improvements, with little focus on CS challenges and requirements. Additionally, CS systems are not being coordinated and tested in an integrated way with operations and intelligence systems. The architecture and requirements for peacetime and wartime logistics and CS information systems will need to be more closely coordinated.

The Air Force has begun evaluating the effectiveness of CSC2 concepts in exercises. Improving CSC2 organizations, processes, and information systems hardware, software, and architecture will require several years of active involvement by US Air Force Headquarters as well as Air Force initiatives to restructure a system that was previously organized around fixed-base, fight-in-place air assets. However, there are active efforts to structure CSC2 activity and policy in a way that should effectively support forces throughout the 21st century. Below is a summary of the status of Air Force implementation actions.

C2 Doctrine. The Air Force initiated a review of its doctrine and policy and began revisions to reflect the robust AEF CSC2 operational architecture. Such actual and planned changes to Air Force doctrine and policy are on the right track. As doctrine is changed, procedures, policies, organizations, and systems can then be changed to align with the changing concepts of warfare. Perhaps the most significant opportunity for improvement is the integration of CS and operational planning. Currently, there are no standard processes for operational planners to communicate operational parameters to CS planners. This deficiency greatly hinders timely, accurate CS planning. Creating a framework, reinforced in doctrine, to delineate specifically what information operations planners provide, in what format, and to whom could address this shortfall. Solidifying this linkage between operations and logistics in crisis action planning would enable a step forward in the coordination, timelines, and accuracy of CS planning.

Improving CSC2 organizations, processes, and information systems hardware, software, and architecture will require several years of active involvement by US Air Force Headquarters as well as Air Force initiatives to restructure a system that was previously organized around fixed-base, fight-in-place air assets.

Organizations and Processes. The Air Force has made progress in establishing standing CS organizations with clear C2 responsibilities and developing processes and procedures for centralized management of CS resources and capabilities.

Training. The Air Force has made much progress in improving CSC2 training, including the formation of an education working group, to address the development and enhancement of formal education programs. The group will also address the implementation of significant new C2 instruction at the Air Force Advanced Maintenance and Munitions Officers School at Nellis Air Force Base, Nevada,[29] and the development of the Support Group Commanders Course and the new CS Executive Warrior Program, which will provide training for support group commanders, who are potential expeditionary support group commanders and A4s.

Information Systems. This area needs the most change. These changes should include the following:

Sense and Respond Combat Support

- Relate operational plans to CS requirements
- Convert CS resource levels to operational capabilities
- Conduct capability assessments and aggregate on a theater or global scale
- Conduct tradeoff analyses of operational, support, and strategy options
- Focus integration efforts on global implementation of a few selected tools
- Standardize tools and systems for consistent integration

The greatest change required in modernized logistics systems is to reorient existing logistics systems toward combat-oriented ones. The peacetime-only materiel management systems need to be structured to participate in the enterprise-wide sharing of data and culling of information.

Most of the logistics information systems' modernization efforts are linked to improving information technology solutions, which support day-to-day business processes. Modernization of the peacetime systems will certainly yield some improved CSC2 information ability. However, the requirements for a more robust S&RCS capability need to be considered within the wartime CSC2 architecture. CS system modernization will need to assess both peacetime and deployment requirements and produce tools and capabilities that will satisfy business processes as well as CSC2 needs.

Enterprise-Wide Systems and Combat Support Command and Control. CSC2 analytical and presentation tools will need to augment typical data processing with increasingly modern sense and respond capabilities. Batch processing and analysis, a proven rate and methodology for most of the Air Force's 60 years of experience, will not effectively support agile combat operations and effects-based metrics. To respond to continuously changing desired effects, enemy actions, rates of consumption, and other controlling inputs, the 21st century logistics warfighter will need to accumulate, correlate, and display information rapidly and in graphic formats that will be equally understandable for operators and logisticians. Data will need to be refreshed much more rapidly than the former monthly and quarterly cycles. Daily decisions will require daily (if not hourly or possibly continuous) data refresh cycles.

A closed-loop planning and control system is essential to a robust military S&RCS architecture. Currently, information about Air Force resource and process metrics is organized by commodity or end item and located on disparate information systems. Creating a single system accessible to a wide audience would enhance leadership visibility over these resources. Such a system needs to have enough automation to translate lower-level process and data into aggregated metrics, which can be related in most cases to operational requirements.

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Stand-alone, single-function systems need to be replaced with systems that serve several functions for CS leaders at all echelons. Finally, modern CSC2 systems need to provide information useful in both peacetime and wartime decisionmaking.

Future Work and Challenges

The Air Force has made some progress toward implementing doctrine and policy changes, and plans are in place to continue to close the information technology and analytical tools gaps. An expanded Air Force *to-be* CSC2 execution planning and control architecture system would enable the Air Force to meet its AEF operational goals. New capabilities include the following:

- Enable the CS community to quickly estimate support requirements for force package options and assess the feasibility of operational and support plans
- Facilitate quick determination of beddown needs and capabilities
- Ensure rapid time-phased force and deployment data development
- Support development and configuration of theater distribution networks to meet Air Force employment time lines and resupply needs
- Facilitate the development of resupply plans and monitor performance
- Determine the effects of allocating scarce resources to various combatant commanders
- Indicate when CS performance begins to deviate from desired states and facilitate development and implementation of get-well plans

CS and operations activities must be continuously monitored for changes in performance and regulated to keep within planned objectives. Significant advances must be made in the way planning, directing, coordinating, and controlling functions are performed to move the Air Force toward a robust S&RCS capability. These essential elements of an effective C2 system must be altered to allow them to accomplish the important aspects of sensing and responding to changes in operating parameters when the violation of tolerance becomes evident. These sense and respond activities will need to take place in a nearly real-time environment.

The objective of rapid sensing and response is to alert decisionmakers to initial deviations in the plan, rather than reacting after-the-fact, to situations affecting mission capability. Emphases of metrics in the future need to be on *outcomes*, rather than on *outputs*. The RAND report details necessary adaptations that include (at the minimum) the following improvements in CSC2 architecture and activities.

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- **Planning.** With the AEF's short time lines and pipelines, it is critical to be able to add CS information to initial planning, giving planners flexibility and confidence. CS execution planning functions include monitoring theater and global CS resource levels and process performance, estimating resource needs for a dynamic and changing campaign, and assessing plan feasibility. Because capabilities and requirements are constantly changing, these activities must be performed continuously so that accurate data are available for courses of action and ongoing ad hoc operational planning.

Sense and Respond Combat Support

Technologies associated with S&RL are still in an early stage of development and may not be fielded for a number of years. Ultimately, ECSS should relate how CS performance and resource levels affect operations, but current theoretical understanding limits these relationships.

- **Directing.** CS-directing activities include configuring and tailoring the CS network, and establishing process performance parameters and resource thresholds.[30] Planning output drives infrastructure configuration direction—there must be an ongoing awareness of CS infrastructure and transportation capabilities to feed into operational planning and execution. Once combat operations commence, the logistics and installations support infrastructure must be regulated to ensure continued support for dynamic operations. The system must monitor actual CS performance against the plan. The performance parameters and resource buffers established during execution planning will provide advance warning of potential system failure.
- **Coordinating.** Coordination ensures a common operating picture for CS personnel. It includes beddown site status, weapon system availability, sortie production capabilities, and other similar functions. Coordination activities should be geared to providing information to higher headquarters to create an advance awareness of issues should one be needed at a later date. Great effort must be made to effectively filter the information flows up the command chain, to avoid overwhelming commanders with information of little utility, but to provide sufficient information to improve battlespace awareness.
- **Controlling.** During the execution of peacetime and contingency operations, CS control tracks CS activities, resource inventories, and process performance worldwide, assessing root causes when performance deteriorates, deviates from what is expected, or otherwise falls out of control. Control modifies the CS infrastructure to return CS performance to the desired state. CS control should evaluate the feasibility of proposed modifications before they are implemented and then direct the appropriate organizations to implement the changes.

Toward a Responsive System

The Air Force has already begun to take steps to implement some of these concepts and technologies with varying degrees of success. Air Force implementation actions include making doctrine changes to recognize the importance of CSC2, as part of S&RCS capabilities, and identifying training and information system improvements.

However, significant challenges remain before the Air Force can realize an S&RCS capability. To develop effective tools that accurately link logistics levels and rates to operational effects, the modern Expeditionary Combat Support System (ECSS) must be developed and tested in conjunction with operations and intelligence systems. Only through integrated testing can the CSC2 architecture be properly developed and implemented.

Technologies associated with S&RL are still in an early stage of development and may not be fielded for a number of years. Ultimately, ECSS should relate how CS performance and resource levels affect operations, but current theoretical understanding limits these relationships. The Air Force does not appear to be lagging

behind industry in the implementation of S&RL capabilities but should continue to make judicious investments in this field.

The Air Force has recently established the Global Logistics Support Center (GLSC) as the single agent responsible for end-to-end supply chain management. The creation of this entity holds promise for the achievement of S&RCS capabilities. The GLSC should be in a position to advocate for future improvements while exploring ways to provide the capability utilizing current systems.

Finally, the observations of the Joint Logistics Transformation Forum are worth repeating: Unless significant improvements are made to *last-mile* transportation in-theater, S&RL will have only a limited effect on operations. A robust, assured transportation network is the foundation on which expeditionary operations, as well as S&RL implementation, rests. The complete integration of transportation into the CSC2 architecture is essential.

Notes

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2. Darius the Great, King of Persia (558-486 BC), and Alexander the Great (356-323 BC) both had to deal with insurgents in their respective empires.
3. Early in its development, the term Expeditionary Aerospace Force (EAF) was used to describe the concept of employing Air Force forces rapidly anywhere in the world, in predefined force packages, called Aerospace Expeditionary Forces. The terms have since evolved and the Air Force now uses the term Air and Space Expeditionary Force to describe both the concept and force packages.
4. Air Force Doctrine Document 2-4, *Combat Support*, 23 Mar 2005.
5. Robert S. Tripp, Lionel A. Galway, Paul S. Killingsworth, Eric Peltz, Timothy L. Ramey, and John G. Drew, *Supporting Expeditionary Aerospace Forces: An Integrated Strategic Agile Combat Support Planning Framework*, Santa Monica, CA: RAND Corporation, MR-1056-AF, 1999.

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6. Air Force Doctrine Document 1, *Air Force Basic Doctrine,* Sep, 1997.
7. James Leftwich, Robert S. Tripp, Amanda Geller, Patrick H. Mills, Tom LaTourrette, Charles Robert Roll, Cauley Von Hoffman, and David Johansen, *Supporting Expeditionary Aerospace Forces: An Operational Architecture for Combat Support Execution Planning and Control*, Santa Monica, CA: RAND Corporation, MR-1536-AF, 2002.
8. The military readers need to equate the word *customer*, in civilian literature, to *operational effects*.
9. Yosef Sheffi, *The Resilient Enterprise: Overcoming Vulnerability for Competitive Advantage*, Cambridge, MA: MIT Press, 2005.
10. See for example: Henry H. Willis and David Santana Ortiz, *Evaluating the Security of the Global Containerized Supply Chain,* Santa Monica, CA: RAND Corporation, TR-214-RC, 2004.
11. David S. Alberts, John J. Garstka, Richard E. Hayes, and David A. Signori, "Understanding Information Age Warfare," *Department of Defense Command and Control Research Program Publication Series*, Washington, DC, 2001.
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15. Leftwich.
16. US Department of Defense.
17. This certainly is not an inclusive list because this is an active research area with numerous initiatives around the globe. Although we will examine a few of these in some detail, projecting the availability of these technologies is beyond the scope of our research.
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24. Bonabeau et al., 2003.
25. Information on DARPA's research is based on personal communications with Dr Mark Greaves, the current Ultra-Log program manager; see also DARPA's Web site: www.darpa.gov.
26. Author's communication with Mr. Edward Boyle, Chief, AFRL/HEAL.
27. Lin et al., 2002.
28. See www.getransportation.com/general/locomotives/services/rm_d/lococomm.asp.
29. Tripp, et al.
30. Major General Kevin Sullivan, "Concept to Reality," in James C. Rainey et al., eds., *Combat Support: Shaping Air Force Logistics for the 21st Century*, Montgomery, AL: Air Force Logistics Management Agency, Aug 2003.
31. Heuristically determined thresholds can be established while more sophisticated expert rules or algorithms are being developed. For instance, Brigadier General Hennessey AMC/LG) uses zero-balance stock positions coupled with forces supporting an engaged combatant commander as a rule to determine when lateral actions should be taken to resupply a unit *at war*. Using this rule, he authorizes the AMC/regional supply squadron (RSS) to reallocate stocks from units with stock to those with zero balances. The idea is to prevent mission degradation by focusing attention on the items that will cause the next mission degradation.

Colonel Walter O. Gordon, USAFR
Colonel Chuck Holland, USAF, Retired

Back to the Future: Airships and the Revolution in Strategic Airlift

The Requirement

The last major study of US airlift requirements, *Mobility Requirements Study 2005* concluded the United States requires an airlift fleet capable of transporting 54.5 million ton-miles per day (MTM/D). Recent developments indicate the requirement will be even higher, perhaps up to 60 MTM/D. According to General John Handy, commander of Air Mobility Command (AMC) and Transportation Command, even meeting the lower requirement requires a C-17 fleet of 222 aircraft, 42 more than the 180 currently under contract.[1] With the Air Force fighting the possible cancellation of the C-130J as well as a significant cutback in the number of F/A-22s, the purchase of 52 more C-17s seems unlikely, much less the number required to meet 60 MTM/D.

Is the C-17 the best way to overcome the airlift shortfall? This article proposes an alternative aircraft—a hybrid aircraft, costing about the same as a C-17, but potentially three times as productive and costing one-half to one-third as much to operate per ton-mile.

An airship obviously has significantly different operating characteristics than an aircraft. Some operating characteristics are better, some are not, and some are just different. Those characteristics will be discussed in this article, but the bottom line is that an airship is probably a viable and affordable alternative to buying additional C-17s and should be considered for filling the airlift gap.

Airship 101- A Brief History

The Flight of the *Luftschiff Zeppelin 59*

In 1917 a German aircraft departed Bulgaria on a 3,600 nautical-mile flight carrying 30,000 pounds of medical supplies and ammunition for a beleaguered army unit in Africa. When it landed 95 hours later it still had 64 hours of fuel remaining—enough

Back to the Future: Airships and the Revolution in Strategic Airlift

From 1923 to 1935 the US Navy operated a total of four rigid airships, Shenandoah, Los Angeles, Akron, and Macon. The loss of three of them to accidents—only Los Angeles retired without mishap—coupled with the loss of the Hindenburg several years later, sounded the death knell for large airship operations.

to have flown to San Francisco had it taken a great circle route west instead of flying south. Nonstop flights from Bulgaria to San Francisco carrying that large a payload could not have been accomplished by a B-29 thirty years later. In 1917, it was closer to the realm of science fiction.[2]

What type of aircraft was this and how was it possible in 1917? It was the German *Luftschiff* Zeppelin *59 (LZ 59)*, a rigid airship. During the flight most of the weight of the ship was held aloft by buoyant lift, the difference in weight between the air displaced by its gas envelope and the hydrogen contained within. As a result, all the engines of the Zeppelin had to do was overcome the drag of the vessel as it passed through the air. The engines on a conventional aircraft must do that as well, but must also overcome the additional drag from the wings lifting the weight of the aircraft.

Graf Zeppelin

Twelve years later, in August 1929, the German airship *Graf Zeppelin* flew around the world in four stops carrying 20 passengers and 41 crew. The longest leg was a nonstop flight between Friedrichshafen, Germany and Tokyo, a distance of over 7,000 miles covered in 100 hours. Not only was a flight like this unthinkable by an airplane in 1929, the passengers made the flight in accommodations unavailable to the commercial air traveler even today (see Figure 1).

The spacious dining room of the *Graf Zeppelin* makes another point about airships. Because the gas envelope is necessarily many times larger than the fuselage of an airplane of comparable gross weight, they tend to have much more volume available for passengers and cargo. It is much more difficult to *bulk-out* an airship than an aircraft.

US Navy Airship Operations

From 1923 to 1935 the US Navy operated a total of four rigid airships, *Shenandoah, Los Angeles, Akron, and Macon.* The loss of three of them to accidents—only *Los Angeles* retired without mishap—coupled with the loss of the *Hindenburg* several years later, sounded the death knell for large airship operations. Looking at the losses of the individual ships, however, one sees that it was not as bad as a simple 75 percent hull loss rate might indicate.

Shenandoah flew 740 hours before being lost in a severe thunderstorm. *Los Angeles* retired with 4,181 hours. *Akron* crashed at sea in a storm due to a faulty altimeter setting with 1,695 hours, and *Macon* ditched at sea with 1,798 hours after her vertical stabilizer was ripped off by clear air turbulence.[3]

Compared to airplanes from the same period these are probably not bad numbers, and when you consider these four rigid airships were the first (and last) the US ever operated, in some ways their record is remarkable—undoubtedly, far better than the first four airplanes. But these losses, coupled with significant advances in airplane technology, enabled aircraft to surpass airships in most areas of operation. This ended operation of the large airship in the United States and the world, at least until today.

Airship Basics

In order to understand the capabilities and limitations of airships certain basic principles must be understood.

Aerostatic Versus Aerodynamic Lift

Unlike an airplane in which lift is generated aerodynamically, the lift required for an airship to leave the ground is produced aerostatically by the buoyancy of the lifting gas in the surrounding ocean of air. A very significant difference between the two is aerodynamic lift costs horsepower and fuel in the form of induced drag, which is roughly proportional to the lift required. This is in addition to parasitic drag—so-called because it does not provide anything useful, like lift—which varies with the square of the velocity of the aircraft and explains why higher speeds require significantly more thrust.

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Aerostatic lift, on the other hand, has no induced drag component. The vehicle is lifted by the buoyancy of the lifting gas and all the engines must do is overcome parasitic drag to move the vehicle through the air. This explains the remarkable performance of airships such as the LZ 59 and *Graf Zeppelin* given the limited performance of the internal combustion engines available at the time. The engines only had to move the airship, not lift it, and since the airships were relatively slow even the parasitic drag component was small.

The two lifting gases historically used in airships are hydrogen and helium. Hydrogen is less dense so it has slightly more lift, about 70 pounds per 1000 cubic feet of gas versus 65 for helium. It is also considerably less expensive. Because hydrogen is highly flammable all contemporary airships use helium. The reason the German airships of the twenties and thirties used hydrogen is because at the time the United States had the only useful supply of helium in the world and was unwilling to sell it to Germany because it was considered a war resource. American airships of the same period all used helium.

Figure 1. *Graf Zeppelin* Dining Room

Rigid versus Nonrigid Airships

From a structural viewpoint, airships may be constructed in two ways, rigid and nonrigid. In a nonrigid airship, which is the only type constructed today, the rigidity of the ship is provided by slight pressurization of the lifting gas. The Goodyear Blimp, or any other blimp for that matter, is a nonrigid airship.

Akron, *Macon*, *Hindenburg*, and all the other great airships of the twenties and thirties were rigid airships, or dirigibles, in which the rigidity of the

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ship is provided by a vast aluminum hull structure completely filling the outer envelope. The lifting gas was then contained within a number of individual gas cells contained sequentially front-to-back within the hull structure. The gas cells themselves had virtually no pressurization. They simply floated against the top and sides of the hull structure to keep the airship aloft.

Rigid airships are much more expensive to produce than the nonrigid variety primarily because of the complexity of the aluminum hull structure. In a nonrigid airship the hull structure consists of both the outer envelope of the ship—which serves double duty as the gas envelope—and the lifting gas itself, which is slightly pressurized to between 1/4 and 1/2 pound per square inch to give the envelope rigidity. To paraphrase a contemporary airship design engineer, "I like helium because it is a great structural material that also happens to lift itself plus more. It allows us to build these hugely large vehicles relatively inexpensively and as a bonus they don't weigh nearly as much as they would if constructed conventionally."[4]

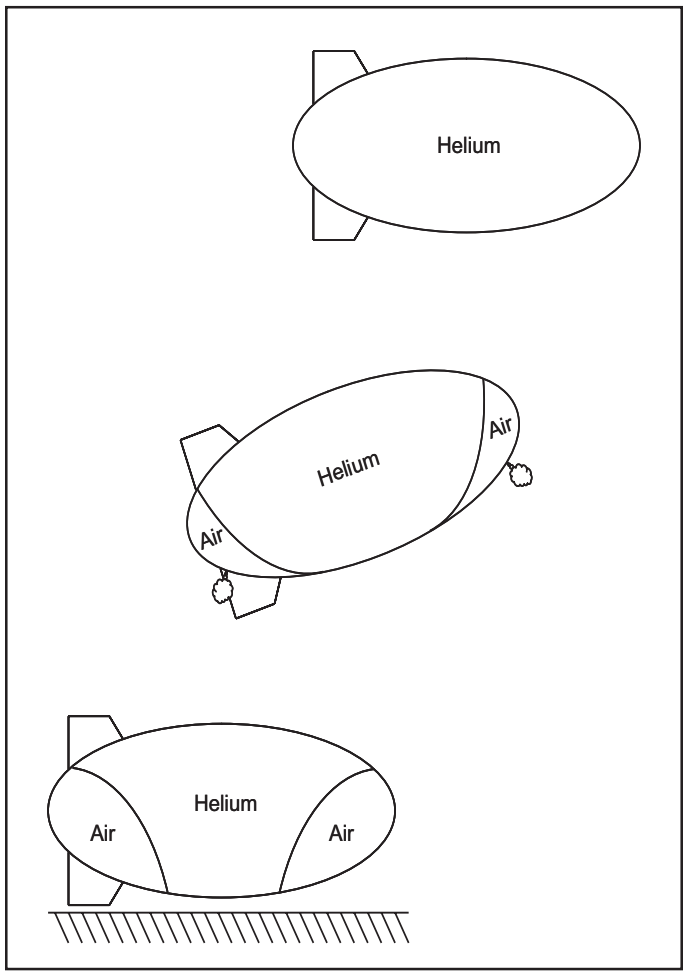

Figure 2. Ballonets at Takeoff, Climb, and Pressure Height

The biggest drawback of a nonrigid is they are limited in size by the strength of the fabric used in the envelope. Even though they are only slightly pressurized, the larger a nonrigid airship gets the greater the stress in the fabric even if the internal pressure remains constant. In the twenties and thirties the state of the art of fabric technology only allowed the construction of small blimps, hence all large airships were rigid out of necessity. Almost all airships proposed for construction today are nonrigid. The balance of this article will refer only to nonrigid airships unless specifically stated otherwise.

Pressure Height

When an airship climbs the lifting gas within it expands as atmospheric pressure decreases. As this occurs the lifting gas must be allowed to expand for two reasons. First, to try to contain it under increasing pressure puts unnecessary stress on the envelope. Though an airship may appear to be highly pressurized, the pressure inside the envelope is maintained only slightly above ambient (less than 1 pound per square inch) to maintain its structural integrity. Second, because the pressure and density of the atmosphere decreases with altitude as the airship climbs, the lifting gas must continue to provide the same amount of buoyant lift and must be allowed to expand to displace additional ambient air.

In a nonrigid airship this is accomplished by incorporating separate, smaller envelopes called ballonets within the main envelope. The ballonets are filled with ambient air and expand and contract opposite the lifting gas (see Figure 2). Before takeoff the ballonets are filled with air and the rest of the envelope with helium. As the airship rises and the helium expands within the main envelope, air in the ballonets is released into the atmosphere and the ballonets contract. The *pressure height* of the airship, which is generally the maximum operational ceiling, is the altitude at which the ballonets are completely emptied of air and helium fills the main envelope. When the airship descends and the helium contracts the ballonets are refilled with atmospheric air to compensate for the shrinking helium and maintain the same relative pressure and total volume of gas within the main envelope.

The design pressure height of an airship is important because it determines the proportion of total envelope volume allocated to air in the ballonets—more air means greater pressure height, but it also means less of the main envelope is allocated to helium at takeoff, which means less lift. An airship that is going to take off at sea level and climb to 10,000 feet en route must have approximately 30 percent of its total envelope volume taken by air in the ballonets at take off to allow room for the expansion of helium during the climb. This means the amount of helium available for lift is only 70 percent of the total envelope volume. If that same airship only had to climb to 3,000 feet, however, the ballonets need only be filled to 10 percent of the total volume so 90 percent could be filled with helium. All other things being equal, this means an airship that had to climb to 3,000 feet on a mission could take off with 28 percent more payload by weight than an identical airship that had to climb to 10,000 feet, the difference the 90 percent helium fill versus 70 percent fill.

This tradeoff must be considered during route planning for an airship, as it could be more efficient to deviate several hundred miles on a transcontinental mission to avoid an 8,000-foot mountain range instead of climbing over it. The additional payload available due to a lower pressure height would probably more than make up for the fuel required by the slightly longer route.

If ballonets are placed fore and aft in the vehicle as illustrated in Figure 2, they may also be used for trimming the aircraft in lieu of aerodynamic trim. Pumping more air into a front ballonet and less out of a rear one while keeping the total volume constant is essentially a transfer of ballast (the air), which shifts the center of gravity of the airship forward. This is more efficient than using aerodynamic trim which increases induced drag that, in turn, increases fuel consumption.

Almost all airships proposed for construction today are nonrigid. The balance of this article will refer only to nonrigid airships unless specifically stated otherwise.

Buoyancy Compensation

Another aspect of airship operations that is not technically obvious is buoyancy compensation. When an airship takes off with neutral buoyancy the aerostatic lift produced by the helium is equal to the total weight of the vehicle—the combined weight of the structure, payload, and fuel. As fuel is burned en route, however, the total weight of the airship decreases but the aerostatic lift remains the same. If nothing is done, over time the ship will gain significant positive buoyancy. As this is

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The elegance of a hybrid aircraft is that it may be designed so an apportionment of aerostatic and aerodynamic lift can completely address the buoyancy compensation problem.

undesirable from both a control and structural viewpoint, the airship must have a mechanism for buoyancy compensation.

Hydrogen-filled airships such as the *Graf Zeppelin* and *Hindenburg* simply vented excess hydrogen into the atmosphere to compensate for the weight of fuel burned. This was an acceptable solution because hydrogen was both inexpensive and easily generated wherever the ships were scheduled to land and refuel. Not so for helium, however, which is considerably more expensive and cannot be generated locally. It must be shipped in heavy steel cylinders from where it was originally mined or subsequently stored. Helium-filled airships such as the *Akron* and *Macon* were constructed with an apparatus on the engine exhaust to condense and recover the water it contained. The water was then stored to compensate for the weight of fuel burned. While a seemingly elegant solution to the en route buoyancy compensation problem, water recovery apparatus was heavy, at least initially unreliable, and the condensers mounted on the skin of the ship added drag. While the equipment improved over time, "the water recovery problem as a whole remained the *bête noire* of the helium-inflated rigid airship."[5]

The other aspect of the buoyancy compensation problem occurs when cargo is offloaded at destination. If an airship arrives at a destination with neutral buoyancy and offloads 30 tons of cargo, it immediately has 30 tons of excess lift. For an airship in commercial operations this is addressed by onloading equivalent ballast, either outbound cargo, water, or both, as the inbound cargo is removed. It can be problematic for a military airship however, as there is often no outbound cargo during a buildup at a forward operating base, and lately many of the deployed operations of the US military have been to regions where large quantities of water are not readily available.

Hybrid Aircraft

Addressing the destination buoyancy compensation problem when ballast is not available is one of the main reasons driving examination of the hybrid aircraft (HA). A hybrid aircraft is an airship in which significant lift is provided both aerostatically and aerodynamically. While all airships generate and make use of a small amount of aerodynamic lift, it is generally only to address minor buoyancy issues en route. The cylindrical fuselage of a conventional airship is optimized for volumetric efficiency of the lifting gas and low parasitic drag, not to generate lift, and they typically take off and land with close to neutral buoyancy. A true hybrid aircraft is designed to take off and land heavier than air, but makes use of aerostatic lift to give part of the weight of the vehicle a *free ride*.

The elegance of a hybrid aircraft is that it may be designed so an apportionment of aerostatic and aerodynamic lift can completely address the buoyancy compensation problem. Assume an airship in which its gross weight consists of 50 percent structure, 25 percent payload, and 25 percent fuel. As a hybrid aircraft, it would be designed so at takeoff half the lift would be provided aerostatically, lifting the fixed structure, and half aerodynamically, lifting the fuel and payload. En route,

as fuel is burned, the angle of attack of the airship (essentially the degree to which it is flying nose up) is reduced proportionally so less aerodynamic lift is generated and total lift remains the same as the gross weight of the vehicle (now reduced for fuel burned). When the HA arrives at destination with a small amount of fuel remaining and the cargo is unloaded, it will still be slightly heavy and not require ballast because the aerostatic lift is still only lifting the structure.

With this added flexibility comes several penalties. First, because it always operates heavier-than-air (think of it as an airplane with subsidized lift), it cannot take off or land vertically or hover. Second, because of the induced drag generated by aerodynamic lift, a hybrid aircraft is less efficient than a pure airship. However, it can still be considerably more efficient than an airplane.

The 21st Century Airship

Background

In January 2004, the Defense Advanced Research Projects Agency (DARPA) published a request for information in the Commerce Business Daily (CBD) for a "Heavy Lift Air Vehicle" capable of carrying "500 tons or more over intercontinental distances."[6] A draft program solicitation released in April contained additional information:

> The baseline mission for WALRUS is to transport personnel and equipment from "Origin to Destination." This mission anticipates loading at a continental US home base and flying strategic distances nonstop to deploy military units in a theater of operations in a fit-to-fight condition. Anticipating local air superiority in the area of landing operations with ground defenses suppressed, WALRUS will land vertically or short rolling at an unimproved site. It will have sufficient fuel and control to take off empty (no external ballast to offset offloaded payload will be required) and to depart the area of hostilities before refueling for return to base.[7]

When the HA arrives at destination with a small amount of fuel remaining and the cargo is unloaded, it will still be slightly heavy and not require ballast because the aerostatic lift is still only lifting the structure.

Strategic distances are specified elsewhere in the document to be up to 6,000 miles.

These requirements are written for an airship. No known or planned airplane can meet the combination of cargo weight, unrefueled range, and ability to land at a short, unimproved site.

A very large conventional airship using buoyant lift could meet all three of those requirements but would require ballast at destination to offset the weight of the offloaded cargo, which is prohibited in the cited paragraph. An alternative to ballast would be to vent helium to reduce lift at an amount equal to the cargo weight. For 500 tons of cargo this would be over a million dollars worth of helium, not something that could be done for normal operations.

A hybrid aircraft would meet these requirements by using dynamic lift to carry the weight of cargo so when it is offloaded it would be neutrally buoyant or close to it, not 500 tons light.

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A significant advantage of the ACLS is it works equally well on land or water, making the vehicle amphibious. Missions could be flown to ships at sea, delivering or picking up cargo that cannot wait for another ship.

The Hybrid Aircraft

Several firms, including Lockheed Martin and Advanced Technologies Group (ATG), a United Kingdom-based airship manufacturer, have proposed pressurized, nonrigid hybrid aircraft in which the shape of the hull is maintained by gas pressure within the envelope. The SkyCat 1000, a 1000-ton payload version, is illustrated in Figure 3. A 500-ton class vehicle would be slightly smaller, but still very large, at approximately 850 feet long, 375 feet wide, and 250 feet high. This may seem large, but it is not much longer than the Akron which was 785 feet long, though it is considerably wider and taller. The Akron had a circular cross-section 150 feet in diameter.

The balance of this article will refer primarily to a 500-ton payload class HA with characteristics derived from several industry sources unless otherwise noted.

Physical Characteristics and Performance

Computed characteristics and performance of a notional 500-ton vehicle are presented in Table 1. The vehicle is designed with a number of unique features to meet the Walrus requirement.

Air Cushion Landing System

The proposed vehicle uses an air cushion landing system (ACLS) instead of conventional wheeled landing gear (see Figure 4). When operating in a reverse, or suction, mode, the ACLS serves to eliminate ground mooring equipment by holding the aircraft firmly against the ground.

A significant advantage of the ACLS is it works equally well on land or water, making the vehicle amphibious. Missions could be flown to ships at sea, delivering or picking up cargo that cannot wait for another ship. The vehicle may also operate like a flying boat, taking off and landing from the water and then taxiing to the shore for onload and offload. If the gradient is shallow enough it could even taxi up onto a beach, removing the vehicle completely from the water much like an air cushion landing craft. On land, the ACLS

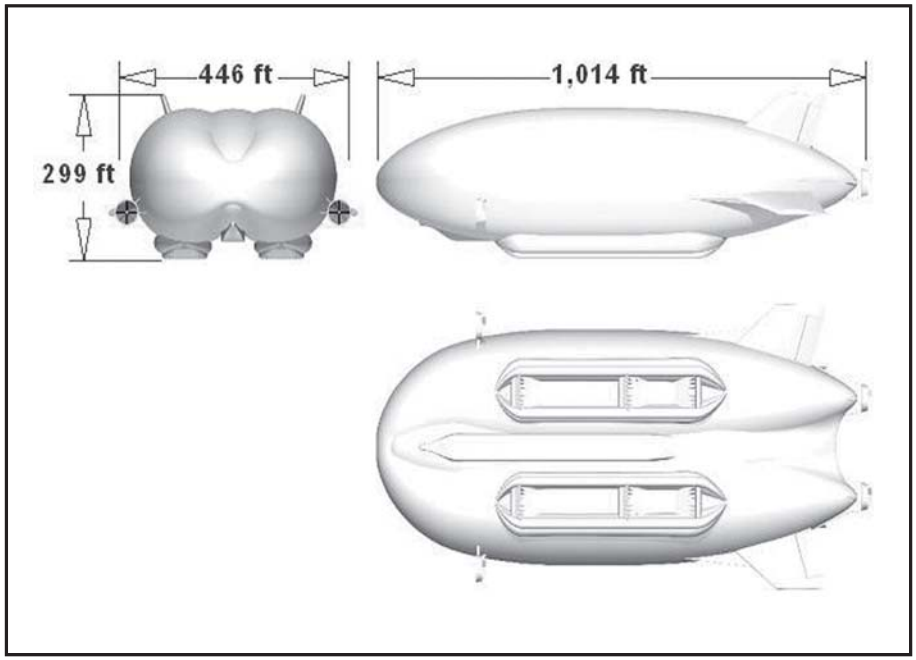

Figure 3. SkyCat 1000

will also work on unimproved surfaces such as flat fields or surfaces covered with ice or snow.[8]

A drawback of the ACLS when compared with a conventional landing gear is that it cannot be used to stop the aircraft, as is the case with wheel brakes. On nonabrasive surfaces such as ice or snow, or on other surfaces in an emergency situation, it may be possible to turn off the outflow of air to lower the skirt to the ground, bringing the vehicle to a stop faster. In normal operations, however, reverse thrust would be used to bring the vehicle to a stop.

In the ATG concept, when the aircraft is parked with little or no wind and it is heavy, the skirt is inflated (the skirt is always inflated on the ground) but outflow from within the ACLS skirt is turned off and the vehicle rests with the skirt on the ground. In higher wind conditions that might cause the vehicle to drag or if the vehicle is light, air is withdrawn from within the skirt, creating a suction to hold the vehicle down.[9] Lockheed's concept is similar, except they feel suction should be continuously on whenever the vehicle is on the ground as it is too susceptible to being moved by a sudden gust.[10]

In flight it may be possible for the ACLS skirt to be deflated and retracted against the fuselage to reduce drag.[11]

Propulsion

The HA is propelled by four gimbaled propeller units (visible in Figure 3). Two are located at the back of the vehicle and one is located on each side toward the front. ATG intends to use four external turboprop engines of the type planned for the A400M airlifter. Lockheed's propulsion system may be similar, though they are also considering using diesel or turbine power generation units centrally located in the vehicle providing DC power to electric motors in thrust pods turning propellers on the exterior. They anticipate several core power units for both redundancy and efficiency. If one fails all four thrust pods will continue to operate. Additionally, when the vehicle is lighter after some fuel has burned off en route, less power is required and one power unit may be shut down intentionally to conserve fuel. The

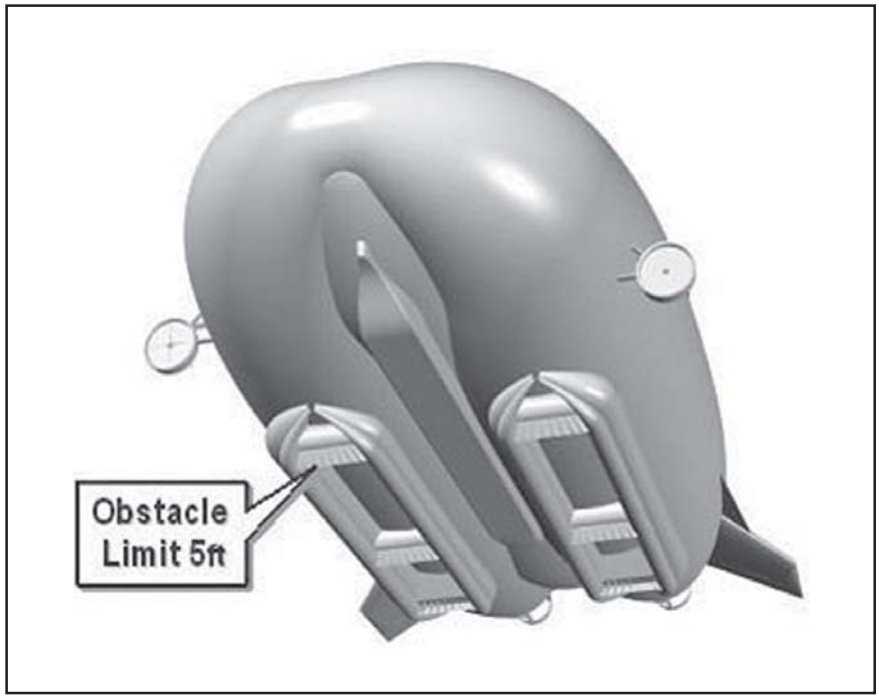

Figure 4. SkyCat Air Cushion Landing System

Characteristics	Performance
Length	850 feet*
Width	375 feet*
*Height	250 feet*
Displacement of envelope	24 million cubic feet*
Volume of helium at sea level	14 million cubic feet*
Cruising speed	80-110 knots
Range	6,000 nautical miles
Ceiling	9,000 feet
Takeoff distance, full load	8,000 feet
Landing distance at FOB	1,500 feet
Cargo weight	500 tons
Fuel weight	300 tons*
Thrust units	Two aft, two side

*** Will vary with specific design**

Table 1. Characteristics and Performance of 500-Ton Payload HA

As the size of a nonrigid airship increases, so does the stress in the fabric. The material required to produce fabric for a 500-ton vehicle is on the borderline of what has been tested in the laboratory but has not yet been made into a flightworthy fabric.

centrally-located power generation scheme offers several other advantages. If future technology provides a more efficient means of generating electricity, such as fuel cells or nuclear power, only the power units need be replaced, the rest of the propulsion system will remain unchanged.

A system to recover water from engine exhaust could be incorporated to provide buoyancy compensation for the fuel burned en route. Such a system would be simpler for centrally-located power units than separate engines mounted on the thrust pods.

Centrally locating the power also makes it easier to manage the heat generated, whether to superheat the helium for additional lift or to reduce the infrared signature of the exhaust to reduce vulnerability to man-portable air defense (MANPAD) systems. Certainly the limited heat generated by the electric motors in the thrust pods will be easier to dissipate than the exhaust of an externally-mounted engine.

Last, a power generation system that has a greater installed weight than a conventional system but uses fuel more efficiently, has the potential to ameliorate part of the buoyancy compensation problem. For example, if externally-located turboprops have an installed weight of 50 tons but burn 200 tons of fuel en route, they generate 200 tons of buoyancy that must be compensated for with ballast or aerodynamic lift. If a centrally-located turbo diesel power plant weighs 150 tons but only burns 100 tons of fuel en route, it only generates a 100-ton buoyancy compensation problem (and hence a more efficient vehicle if it is accounted for by aerodynamic lift) even though the total weight of the propulsion system plus fuel is the same as the turboprop installation.

Thrust Vector Control

In order to meet the short-field landing requirement, the HA is capable of landing and taking off at extremely low speeds on the order of 25-35 knots. At these speeds

there is not enough dynamic pressure over reasonably sized aerodynamic control surfaces to adequately control the vehicle, so it is done with thrust vector control of the thrust pods. The side propeller units gimbal ±90 degrees vertically for pitch control, while the rear units gimbal 60 degrees in all directions for pitch and yaw control.

Risk Areas

While the original DARPA CBD announcement did mention the possible investigation of some fairly esoteric technologies, they are not required for the hybrid design proposed in this article. Certain technologies are, however, of medium risk.

Envelope Fabric

As the size of a nonrigid airship increases, so does the stress in the fabric. The material required to produce fabric for a 500-ton vehicle is on the borderline of what has been tested in the laboratory but has not yet been made into a flightworthy fabric. This is considered to be a medium risk area. The joint technology used to join the cut pieces of fabric together to make the large envelope also must be proven at the higher stress level associated with a larger vehicle.[12]

Air Cushion Landing System

The ACLS is going to be an active structure, operating continuously while the vehicle is on the ground, either in the hover mode if the vehicle is taxiing or taking off, or the suction mode if it is stationary. Since the ACLS serves as the airship's mooring system, the worst-case consequences of it failing are quite serious. Imagine a 350-ton (or more) vehicle the size of an aircraft carrier blowing down the block.

The vulnerability of airships to surface winds is illustrated in Figure 5. A series of photographs showing the *Los Angeles* (all 75 tons and 650 feet of her) swinging over the mooring mast when a wind and temperature shift raised the tail of the ship before the crew could compensate. It is worth noting that even though the incident appears very dramatic, the damage to the ship was incidental and it could have been flown away immediately after, if necessary.[13]

Lockheed feels the ACLS is also a medium risk item; not because of any new technology required, but because nothing like it has been built before for this application and a significant amount of new engineering is required.[14]

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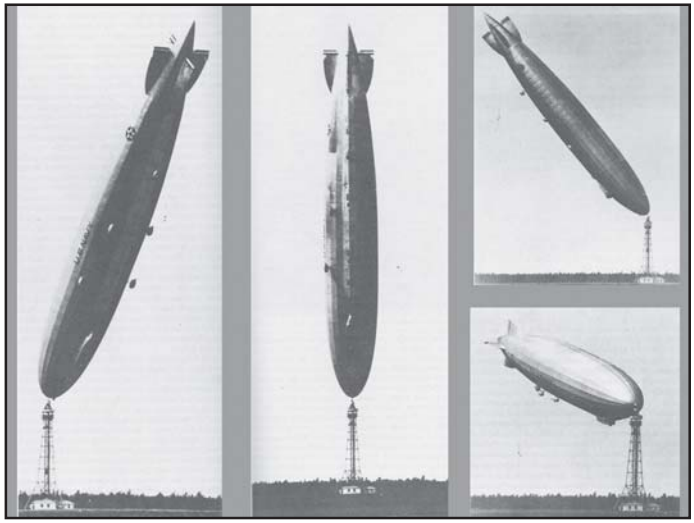

Figure 5. *Los Angeles* on End

The takeoff area required for a fully loaded HA with 500 tons of cargo and 300 tons of fuel is estimated to be 8,000 feet.

Flight Control System

The HA must have a digital flight control system both to eliminate excessively long cable runs and also to reduce the workload for the pilot of what would be a sluggish, difficult-to-control aircraft. The use of thrust vector control combined with conventional control surfaces, both in flight and for maneuver on the ground, would also increase the workload of the pilot, probably excessively so, if not managed by a computer.[15]

Operational Considerations

Runway Requirements

The HA is designed to take off and land directly into the wind, so it does not have crosswind limits. It does require rectangular or circular landing zones. The takeoff area required for a fully loaded HA with 500 tons of cargo and 300 tons of fuel is estimated to be 8,000 feet. An 8,000-foot concrete circle or rectangle may seem like a lot, but recall that because of the capabilities of the ACLS, operation from a runway is not required. The vehicles will typically operate from the water if leaving from a sea port of debarkation (SPOD) or from a drop zone if leaving from an Army base, a conventional aerial port of debarkation would normally not be used.

The landing area required at destination when most of the fuel is burned off is estimated to be 1,500 feet. Again, circular or rectangular landing areas are required so the aircraft can land and take off into the wind.

Winds Aloft

The relatively low true airspeed of a hybrid aircraft makes it especially vulnerable to increased transit time due to headwinds, so much so that significant deviation from the most direct route in pursuit of tailwinds can have a large benefit. For example, a 100-knot HA flying into an average 20-knot headwind would take 58 hours to fly 4,600 miles along the ground, the great circle distance from the West Coast of the US to Korea. If by deviating 1,000 miles around circulating weather patterns the 20-knot headwind is turned into an average 20-knot tailwind, the trip would only take 47 hours, a half day less of transit with significant fuel savings as well. In fact, because the HA is capable of such significant deviation to take advantage of tailwinds and mitigate the effect of headwinds, the presence of real-world wind on a given route would not increase transit time more than 5 percent and almost always results in lower total time for a round-trip flight.[16]

Terminal Weather

The Sky Cat 1000 report gives the ceiling and visibility requirements for the vehicle as a 200-foot ceiling and zero visibility, or "0/0 for military fields with precision approach radar capability."[17] While these figures may be correct, one needs to keep in mind that the landing zones (and water areas for SPODs) from which the vehicle is going to operate will often not have instrument approaches, so the vehicle will not always be able to operate in such poor weather. Even if self-contained Global

Positioning System/inertial navigation system approaches are constructed on the fly for a tactical landing zone they will still not have received either the level of scrutiny with respect to obstacles in the area or the flight inspection of a conventional approach.

Weather Hazards

Like any aircraft, the HA would seek to avoid thunderstorms, and equipped with an onboard weather radar and real-time weather information would be able to do so.[18] Studies anticipate the aircraft would be damaged, but not brought down should it be struck by lightning. Several means of adding conductive material to the envelope to further ameliorate the effects of a lightning strike have been discussed but would add cost and weight to the vehicle that are not included in the estimates presented in this report.[19]

In-flight icing would be addressed by a number of anti-icing and deicing measures similar to conventional aircraft. Ice accumulation while the aircraft is parked on the ground could be a significant problem as the vast area of the envelope means even a thin coating of ice would have significant weight. Conventional deicing by truck would be almost impossible because of the large size of the HA. A mechanism could be designed into the vehicle to disperse anti-icing solution over the envelope but this would have its own set of issues regarding the quantity of fluid required and whether it would have to be recovered because of environmental concerns. It would be simplest if the vehicle was flown away during prolonged icing conditions on the ground.

Snow accumulation while parked is less of a concern than ice because of its reduced weight. The HA could actually take off supporting a thin layer of snow and buildup in excess of that could be prevented by high-speed taxiing.

The amount of aerostatic lift allowed for a particular mission is limited by the requirement for the vehicle to be slightly heavy before departing the forward operating base after the cargo is offloaded.

Ballast

While one of the main reasons for employing a hybrid aircraft is to eliminate the need for buoyancy compensation ballast, the efficiency of the vehicle can be improved if ballast is available when the cargo is offloaded or even earlier in the flight after some of the fuel has been burned off. The reason is simple but probably not intuitive. The amount of aerostatic lift allowed for a particular mission is limited by the requirement for the vehicle to be slightly heavy before departing the forward operating base (FOB) after the cargo is offloaded. When the vehicle is required to operate with no ballast, this lift is equal to the empty weight of the HA plus any remaining fuel at that point. For a 300-ton empty weight HA with 25 tons of fuel remaining that would be 325 tons. As a result, before initial departure from home station the amount of air in the ballonets would have to be adjusted to 325 tons of aerostatic lift even if the total gross weight of the vehicle at the time was several times that with cargo and fuel load. The balance of the lift en route would have to be provided aerodynamically, which is not as efficient.

Compared to a C-5 or C-17, the probability of kill given a hit by anything except the largest surface-to-air ordnance is lower for an airship than an airplane. Large surface-to-air missiles, such as the SA-6 or SA-10, would probably bring down an airship as they would an airplane, but even then, because of its extreme size and lower speed, the airship might be able to land under some semblance of control where an airplane would simply come apart.

If ballast may be taken on to offset fuel burned at some point in the mission, however, initial aerostatic lift may be increased to reflect the weight of the ballast, because after the cargo is offloaded at the FOB the ballast is still present to prevent the vehicle from having positive buoyancy. If in this same example the vehicle was able to land on the ocean, prior to coasting in at the destination landmass, and onload 100 tons of ocean water ballast, the aerostatic lift at initial takeoff could be adjusted to 425 tons instead of 325, making for a more efficient flight profile, requiring less fuel overall.

Mission Effectiveness

The bottom line for acquisition of a fleet of hybrid aircraft simply comes down to mission effectiveness and cost. Will it get there soon enough, safely enough, and with enough stuff? Is it more economical to acquire and operate than the competition?

Vulnerability

The first question most people ask when told about using airships for strategic lift is, How vulnerable is it? The answer to that question is, Much less than you would think, but it depends on the situation and what you are comparing it to.

Compared to a waterborne ship, an airship is less vulnerable because over the ocean it is almost always safer to be several thousand feet in the air than on the surface of the water. Threats from mines, torpedoes from submarines or surface vessels, surface-to-surface or air-to-surface anti-ship missiles, suicide speedboats, or boarding by pirates simply do not apply to an airship. Those things that could threaten an airship, such as fighter aircraft or surface vessels armed with surface-to-air missiles or artillery (and the airship could easily detect and avoid or outrun the latter if they were perceived to be a threat), would be just as threatening to surface vessels. So even from a brief qualitative analysis it is readily apparent that only a small subset of the possible threats to surface ships could threaten an airship.

The comparison is a little more complicated when made against other aircraft. Compared to a C-5 or C-17, the probability of kill given a hit by anything except the largest surface-to-air ordnance is lower for an airship than an airplane. Large surface-to-air missiles, such as the SA-6 or SA-10, would probably bring down an airship as they would an airplane, but even then, because of its extreme size and lower speed, the airship might be able to land under some semblance of control where an airplane would simply come apart.

For simplicity the vulnerable area of an airship may be divided into three categories.

- Envelope
- Fuselage
- Propulsion units

Should the envelope be hit by antiaircraft artillery (AAA) projectiles that do not detonate but simply make holes, the effect would hardly be noticeable. Because of the extremely low pressure of the lifting gas, the rate of exchange between helium and ambient air across even hundreds of 23 mm holes would not prevent the airship from completing its mission and flying to a safe location to be repaired, if not even back to its home base. Even if a MANPAD were to detonate against the envelope instead of punching a hole in it, the resulting hole would be much more significant, but it would still take hours, not minutes, to bring the airship down. And it would land, not crash.[20]

If the fuselage were struck by AAA it would certainly detonate, but industry designers believe they could allocate sufficient weight to incorporate Kevlar armor under the entire fuselage designed to protect it up to direct hits from 23 mm AAA.

If a MANPAD were to strike one of the four propulsion units it would probably destroy it. As with a four-engine airplane, however, the HA is capable of maintaining flight with only three propulsion units. In fact, only two are necessary in most circumstances as long as they are on opposite sides. The likelihood of a MANPAD striking the propulsion unit is open to question, however, if the HA has a central power generation system in which power is generated in the center of the fuselage and routed to electric motors in each propulsion unit. The electric motors would have a much lower infrared signature than a turbine engine, and the heat from the central generation unit would either be vented out the top of the airship or used to heat the lifting gas several degrees for extra lift. The HA would also be able to be fitted with large aircraft infrared countermeasures that would further reduce its vulnerability to MANPADs.

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The above discussion applies to the probability of a kill given a hit. However, the vulnerability of an airship to a hit is unquestionably higher than an airplane. While a C-5 or C-17 cruises above all except the largest surface-to-air threats and is only exposed to smaller ones in the terminal environment, an airship cruising at 9,000 feet over land is exposed to everything, except small arms. This is the long pole in military airship vulnerability and except for the protective measures outlined above there is no getting around it. If there is a threat along the route of flight, efforts would have to be taken to ameliorate it as much as possible by flying at night and avoiding threats to the greatest extent possible. This effort would be aided by the fact that unlike a large airplane, which has to head for a runway near which threats could be placed, the airship can land anywhere there is a 1,500 foot diameter circle of unobstructed ground, significantly complicating the enemy's targeting problem.

Notional Scenario

The results of an industry study of the deployment of a Stryker brigade combat team (SBCT) from Fort Lewis, Washington, to Kimhae Airbase (AB), Korea, are shown in

Back to the Future: Airships and the Revolution in Strategic Airlift

Critics dismiss airships out of hand because they are not capable of flying over medium altitude threats as airplanes can. The utility of airships is more readily apparent, however, if one considers them not as a replacement for the C-17 but as a vehicle with the payload of a small ship that flies several thousand feet over the ocean at 100 knots, and can then proceed inland as far as the threat will permit, and land in a large field. They would constitute a valuable third mode of strategic transportation for USTRANSCOM with speed much better than a ship and economics much better than an airplane.

Table 2. The study compares 30 HAs against 63 C-5s. The much slower HAs have a slight edge in total deployment time, 96 hours against 102 hours for the C-5s, because the 500-ton payload HAs need only make one trip versus three for the 130-ton payload C-5.

From a cost standpoint, though a detailed cost comparison is outside the scope of this article, the HAs have a 3:1 advantage in fuel burned to accomplish the mission. Even in acquisition cost, the price to purchase 30 HAs, about $6B, is only 50 percent more than the $4B cost to the Reliability Enhancement and Reengineering Program for the 63 C-5s that are already in the inventory. If the comparison was made between buying 30 HAs and buying the 90 C-17s needed to accomplish this mission in the same length of time, the difference in cost is quite significant as it is estimated a 500-ton payload class HA would cost about the same as a C-17.

The ability of the HAs to operate from completely unimproved surfaces such as open fields also gives the Army more flexibility in the deployment than the C-5s. In this scenario the HAs could be operated from the drop zone at Fort Lewis, which is potentially more convenient than transporting the SBCT the 15 miles to McChord Air Force Base to be loaded on the C-5s. Similarly, when the HAs arrive in Korea they would not have to land at Kimhae AB should it be occupied to capacity by other aircraft. With full payload, but only destination fuel (fuel to fly 500 more miles) the HA is capable of operating out of a 1,500-foot circle, so if the Army wants the SBCT inserted closer to their eventual destination the HA should be able to do it.

Conclusion

Over the next several years the US Department of Defense has some very hard decisions to make regarding strategic airlift. If funding is not available to meet 54.5 MTM/D or more with conventional airlift, either sacrifices in capability must be made or an alternative will have to be found. This article presents a potentially viable alternative in the form of a hybrid aircraft.

When the author spoke to a United States Transportation Command (USTRANSCOM) officer to gauge their interest in airships he was told, "We looked at that a few years ago but dismissed it because none of the players were real companies." Today, a key player in airships is Lockheed Martin, one of the largest aerospace companies in the world. On the other hand, AMC, and therefore to a certain

	HA	C-5
Number of aircraft	30	63
Number of flights	30	188
Cruise (knots)	100	490
Total time (hours)	96	102
Fuel (million pounds)	30	89

Table 2. Operational Comparison of HA versus C-5

extent USTRANSCOM, is currently working very hard to purchase a C-17 fleet of at least 222 aircraft and may not be interested in alternatives.

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Air Vice-Marshal Peter J. Dye, RAF

Sustaining Airpower: Influence of Logistics on RAF Doctrine

Introduction

In 1942, Sir Frederick Sykes, the first commander of the Royal Flying Corps (RFC), and later chief of the Air Staff, briefly outlined how the motto, *Per Ardua ad Astra* (Through Adversity to the Stars), had been selected. Although he noted that some thought it bad Latin, he did not choose to elaborate on why it was the *best possible choice*.[1] For Sykes and his contemporaries, the reasons would have been self-evident. The RFC had emerged in the face of institutional hostility, interservice rivalry, political indifference, and significant technical and environmental challenges. The struggle to master the air had exacted a heavy price. The ethereal (the heavens) had been gained through human (mortal) effort. But, there was perhaps an even deeper message—the paradox that was the aspirational nature of airpower and the laborious, sometimes mundane and frequently complex arrangements needed to support military aviation. Thus, while the bravery and dedication of those individuals who helped to create the RFC was not in question, it was evident that the freedom of the skies (and the boundless military potential they offered) was in stark contrast to the fragility (often literal) of powered flight.

This article explores how the question of sustainability has influenced British thinking on airpower. It explores the often-troubled relationship between support activities, particularly logistics, and the delivery of military capability. The article also touches on organisational and cultural issues, and considers how current paradigms may change with the increasing focus on expeditionary warfare and the development of network-enabled capability.

Sustainability and Logistics

Logistics and sustainability are not the same thing, although there is sometimes an implication that they are. Strictly speaking, sustainability is the "ability of a force

Sustaining Airpower: Influence of Logistics on RAF Doctrine

The cost, complexity, and effort needed to sustain military aviation are considerable. Air forces have learned how to manage these activities by focusing on process and organisation, but there remains a suspicion that the logistician is as much an impediment as an enabler in the delivery of airpower.

to maintain the necessary level of combat power for the duration required to sustain its objective."[2] Logistics, as the science of planning and carrying out the movement and maintenance of forces, clearly contributes to sustainability, but then so do training, intelligence, planning, and a wide range of other support or enabling activities that are certainly not embraced by the term *logistics*.

Sustainability is now properly regarded as a *principle of war* and, while logistics activities are hugely important in contributing to this core capability, they are subordinate to this end, together with the associated support strategies and organisational arrangements.

Enabler or Impediment?

Military aircraft spend much of their working lives parked comfortably on the ground, protected from the very elements that they supposedly conquered at the turn of the 20th century. It is not just gravity that keeps them there. The cost, complexity, and effort needed to sustain military aviation are considerable. Air forces have learned how to manage these activities by focusing on process and organisation, but there remains a suspicion that the logistician is as much an impediment as an enabler in the delivery of airpower. For example, does the supply chain drive the machine forward or drag it back? Current sentiment seems to prefer the latter perspective. The popular press certainly seems unable to employ the word *logistics* without the juxtaposition of *failure*, *shortage,* or *crisis*.

These views are neatly encapsulated in Hoffman Nickerson's observation that "*Airpower is a thunderbolt, launched from an eggshell, invisibly tethered to a base.*"[3] Dramatic effect is balanced by a sense of fragility while still leaving one to wonder whether the tether should be viewed as an umbilical or as a brake.

Organisational Egg or Doctrinal Chicken?

To address the question of how sustainability has influenced British thinking about airpower we need first to confront the conundrum of what came first, the doctrinal chicken or the organisational egg? The widely used Doctrinal Development Model suggests that the process is best seen as a continuous loop, linking doctrine, output, feedback, and input. While this may be an entirely adequate concept, it does beg the question of what came first? My personal view is that logistics processes have so dominated the delivery of airpower that doctrine has largely followed in their wake. This is as true today as it was when the Royal Air Force (RAF) was created.

The First World War

On the morning of 7 April 1918, with the airfield at La Gorgue shrouded in heavy fog and the German army advancing, Major Chris Draper ordered the burning of all 16 Sopwith Camel fighters belonging to No 208 Squadron, RAF. Two days later, the squadron had relocated to Serny, over 20 miles to the west, and was actively engaged in the continuous air operations that sought to halt the German march

offensive before it could threaten the channel ports. As the squadron commander later recalled, "It says a lot for the supply depots that we got our full complement of 20 new machines within 48 hours."[4]

This small incident, in a long and intensive war, provides some indication of the scale and effectiveness of the logistics system that underpinned the British air effort on the Western Front. The value of the machines burnt at La Gorgue represented £5M at today's prices, yet new aircraft were available almost immediately, as were the technical personnel, ground equipment, spares, fuel, ammunition, vehicles, tools, repair facilities, and hangarage needed to support a frontline squadron.[5]

The First World War and its aftermath largely shaped the 21st century. In scale and intensity it was quite different from any other war previously fought. It was also a conflict in which technology dominated events to an unparalleled degree. John Terraine has observed that "the Great War was from the beginning the greatest war of technical innovation ever fought," adding that modern wars had become—as a war of masses with modern weapons sustained by modern mass production— "a matter of organisation and specialist skills in all the complex areas of logistics."[6]

It is arguable that the most complex logistics challenge was faced by the air services as they sought to realize the potential of airpower. Over recent years there has been a gradual recognition of the immense and sophisticated efforts needed to sustain the Western Front, as part of a more balanced and dispassionate analysis. The air war has not attracted the same level of interest, let alone controversy, even though it presaged the great air offensives of the Second World War. In fact, there has been a remarkable lack of debate about how, in a matter of a few years, a pre-war novelty was turned into a weapon capable of influencing the course of battles and ultimately war itself.

Between 1914 and 1918 the air arms of all the major belligerents, with the exception of Turkey, underwent a revolutionary transformation, but none more so than the British Air Services. By the Armistice, the RAF possessed 22,171 aircraft and boasted a total strength of 274,494 personnel compared to the RFC and Royal Naval Air Service combined strength of 270 aircraft and 2,073 personnel on the outbreak of war.[7] The RAF also possessed, according to the author of a post-war study, the most fully developed system of aviation supply amongst the allies.[8]

There is some danger, however, in focusing just on the gross number of aircraft. It masks a fundamental characteristic of airpower—the high ratio of support to operational activities. If the frontline squadrons were the RAF's cutting edge of the spear, the shaft represented the greater part of the weapon. Of the 22,171 total aircraft, just 6,740 were assigned to operational duties (including the Western Front, home defence and antisubmarine activities). However, only 2,896 could be regarded as effective (13 percent of those on charge)—the remainder being held in store or under repair intheatre. At any one time, a further 10 to 15 percent were unserviceable, leaving just 2,500 aircraft to be employed on active operations. While much of the difference is explained by the need to hold significant reserves against attrition,

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The First World War demonstrated that sustaining an effective air force required significant economic and industrial power allied to a large and complex support organisation.

the number of operational aircraft was unquestionably modest compared to the total inventory (see Figure 1).[9] The scale of the resources needed to sustain this frontline (equivalent to some 200 squadrons in 1918) was unprecedented. Indeed, the national effort was substantially larger than the total uniformed strength of 274,494 implies. When the civilian labour involved in aircraft and aeroengine production, provision of spares and repair is taken into account, the number of personnel required rises to around 630,000 (including trainees, instructors, and support staffs).[10]

By the Armistice, the total cost to the nation, in materiel and human terms, amounted to the equivalent of £200M per year, or 4 percent of the United Kingdom's gross domestic product (GDP). Daily expenditure on the RAF had reached over £0.5M, or 7 percent of Britain's total daily war expenditure (see Figure 2). This was set to rise still further with some £165M of outstanding aviation orders, more than half the production commitments of the Ministry of Munitions, at the time of the Armistice.

The result of this huge investment was the production each month of an average of 4,000 aircraft, 3,900 aeroengines (including those repaired or rebuilt), 1,200 pilots, and 3,000 other ranks. Without this effort, average monthly losses of 2,200 aircraft and 3,000 aeroengines (written off and damaged), and some 800 to 900 pilot casualties would have rapidly curtailed operations.

The logistics system embracing these varied activities had few, if any, parallels in history. By the Armistice, the RAF's technical inventory comprised more than 50,000 separate line items. No business ever had to manage a stock holding of this size or complexity—a challenge made all the more difficult by the delicate nature of much of the equipment and spares involved, rapid obsolescence, and high modification rates.

Organisational Implications

The First World War demonstrated that sustaining an effective air force required significant economic and industrial power allied to a large and complex support organisation. It is not surprising, therefore, to find that the level of increase in resources committed to the air services was significantly greater than to the Army (see Figure 3). Trenchard's strategy of the *relentless and incessant offensive*[11] was only tenable because the necessary human and material resources were made available.

It was known before the war that the arrangements needed to support military aviation possessed quite distinct characteristics. Sefton Brancker described, in June 1914, how the difficulties of maintenance were sometimes lost sight of, and that the fragility of aircraft, the need for repair and large quantities of spares, together with the difficulty of supply meant that "only a small proportion of the aeroplanes in the field will be fit to take to the air at any given moment."[12] In fact, sustainability was a major consideration in the decision to standardise on the squadron as the basic organisational building block for the RFC and, ultimately, for the RAF.[13]

Wastage rates were high as a result of accidents and low reliability, as much as from enemy action. This demanded a constant stream of replacement aircraft and aircrew. The disparity between new production and supply, particularly in aeroengines, meant that salvage, repair, and maintenance made a significant contribution to sustainability. Obsolescence, design and manufacturing shortcomings, and shortages in critical equipment meant that a high level of modification and rework had to be undertaken in the field. A wide range of special equipment, tools, and a myriad of individual parts and components needed to be readily available to the frontline squadrons to support these activities, as well as routine maintenance—under the constant threat of a short-notice move. The result was an extensive ground organisation, employing large numbers of skilled and semi-skilled personnel, underpinned by a supply chain that stretched from the frontline, via the repair depots and air parks, to the factories at home.

Aircraft and their component parts largely populated the supply pipeline, together with a constant flow of technical information, spares, equipment, and personnel. Unlike traditional military logistics systems, it was not dominated by a one way flow of consumables but by scarce, high value items that moved to and from the frontline in a constant cycle of replacement, salvage, and repair.[14] As a result, noncombatants greatly outnumbered combatants. This was no subtle shift in the balance of roles, but a steep change in the *teeth-to-tail* ratio. Thus, of the 51,000 RAF uniformed personnel serving in France by November 1918, only 8 percent were classed as combatants (pilots, observers, air gunners, and so forth) while the majority, some 29,000 (57 percent) were technicians. By comparison, 896,000 personnel (65 percent) of the British Army were classed as combatants (see Figure 4).

The other defining feature was the balance of expenditure between personnel and equipment. During the course of the war over 50,000 aircraft were delivered to the British Air Services, of which only 36 percent remained on charge by the Armistice (see Figure 5). In 1918, squadron frontline establishments were replaced on average every 2 months. Notwithstanding the importance of repair and salvage in helping to recycle aircraft, aeroengines, and components, huge sums had to be committed to sustain the frontline. Throughout

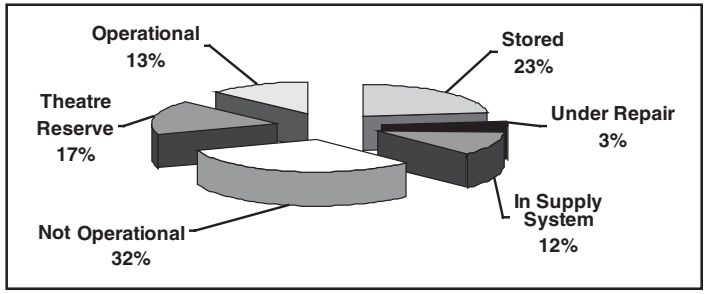

Figure 1. RAF Aircraft Dispositions November 1918

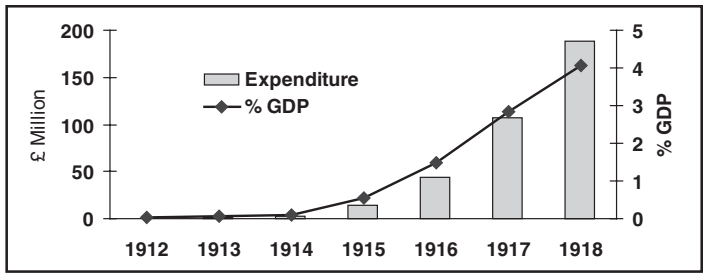

Figure 2. Aviation Expenditure 1912-1918

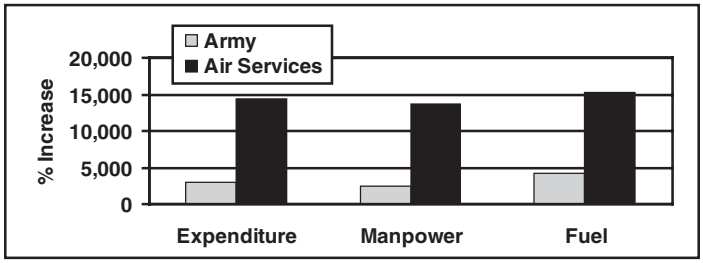

Figure 3. Relative Increase in Military Resources 1914-1918

Sustaining Airpower: Influence of Logistics on RAF Doctrine

The expansion of the RAF from 1934 onward, although overtly dominated by the need to match the Luftwaffe's frontline, also sought to provide the resilience needed to fight a modern war. This was not a policy of quantity over quality, although there was some criticism (from even within the Service) that there were dangers in pursuing the mass-production methods employed in the First World War.

the war, between 50 and 60 percent of the budget allocated to the British Air Services was expended on equipment (see Figure 6).

In summary, the RAF was created around a system of interlinked and interdependent logistics activities that moved high value materiel continuously backwards and forwards at a tempo determined by daily attrition, combat operations, and technological advances—John Frederick Charles Fuller's *constant tactical factor*.[15] It was a system unprecedented in both scale and intensity. Moreover, the efficiency and effectiveness of these arrangements directly governed the degree to which air power's potential could be realised. In this sense, logistics acted as air power's *lifeline* and, in so doing, established a dependency that has lasted for 90 years.

The Creation of the Royal Air Force

Concerns about sustainability also provided the catalyst for the creation of the RAF. The political imperative for an offensive air strategy and secure home defence could only be realised by the deployment of substantial national resources and closer military-industrial cooperation. The Joint War Air Committee formed early in 1916 (and the subsequent Air Board) were direct responses to the squabbling between the Services over the supply of aircraft and engines and the self-evident need to set priorities for the allocation of aeronautical material. Inasmuch as this established a favourable environment for an independent air arm, it may be claimed that the RAF was created as a structural solution to the wartime problem of maintaining an adequate supply of aircraft and aviation personnel.

Strategic Bombing

The creation of the Air Board and the more effective direction of production under the Ministry of Munitions saw significant improvements in sustainability. Indeed, the expectation of a surplus in aircraft and aeroengine production by the end of 1917 led directly to the creation of the Independent Force intended to attack military and strategic targets in Germany. In the event, the full increase in production was not achieved but by then the Independent Force had been created to employ the notional surplus of men and machines. Eventually, some 10 squadrons out of the planned 40 were formed. Even if the numbers employed fell short of those planned, and the operational results lacklustre, the experience had a profound influence on RAF doctrine. Thus, an optimistic view of sustainability in 1917 led to the RAF's first steps in strategic bombing and, ultimately, to the Second World War's combined bomber offensive.

The First World War Legacy

I have laboured the point about the interdependence of airpower and logistics because the nascent RAF, at an organisational level, was designed around the support arrangements needed to sustain operations in war. While there was no *lessons*

identified process, the central role of logistics in the delivery of airpower was widely recognised and understood. Air Commodore Robert Brooke-Popham, lecturing shortly after the end of the First World War, stated that,

> It is, therefore, of the highest importance that spare machines and spare parts of every sort shall be instantly available. This means large base depots and an efficient channel of supply between depots and squadrons and on the sound working of this supply system the efficiency of the Air Force in any theatre of war very largely depends.[16]

In the years that followed, Trenchard sought to construct (literally) an air force worthy of the name. The RAF Cadet College and the RAF Apprentice School were the most obvious elements in this strategy, but they were part of a wider programme that enshrined a logistics-centric view of airpower based on a substantial investment in support activities. Speaking in 1944, Trenchard recalled that,

> When we originally formed the Air Force in those days we were told that we were spending all our money on bricks and mortar, and on ground staff and ground personnel. In fact … it was called *the Ground Force* and I believe I was myself once described as *General Officer Commanding Ground Force*.[17]

The importance attached to organisation and process was reflected in the RAF War Manual. "Under the modern conditions in which fighting services are called upon to operate, victory inclines to the force which is most thoroughly and efficiently organized."[18] A recurrent theme in pre-war planning was the high wastage that war would bring. In a paper on *Some Problems of a Technical Service* read at the Royal United Services Institute in 1934 (with Air Marshal Sir Robert Brooke-Popham in the chair), the author stated that the average life of an aircraft in war would be 2 months—based on First World War experience—and that large reserves and high production rates were essential, underpinned by long preparation and skilled repair personnel.[19]

Thus, the expansion of the RAF from 1934 onward, although overtly dominated by the need to match the Luftwaffe's frontline, also sought to provide the resilience needed to fight a modern war. This was not a policy of quantity over quality, although there was some criticism (from even within the Service) that there were dangers in pursuing the mass-production methods employed in the First World War.[20] By and large, new technology was successfully introduced while substantially increasing

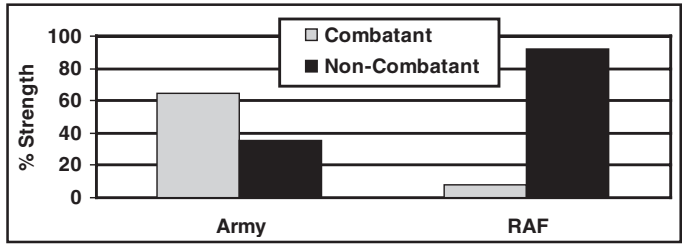

Figure 4. Relative Proportion of Combatants - France 1918

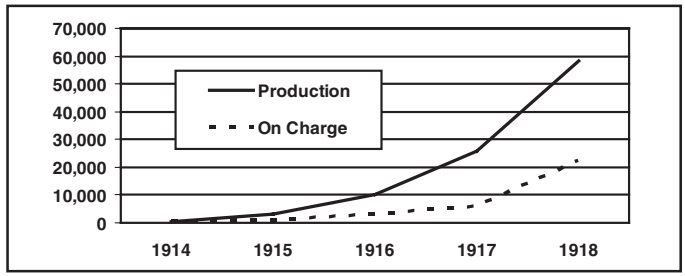

Figure 5. Aircraft on Charge - British Air Services 1914-1918

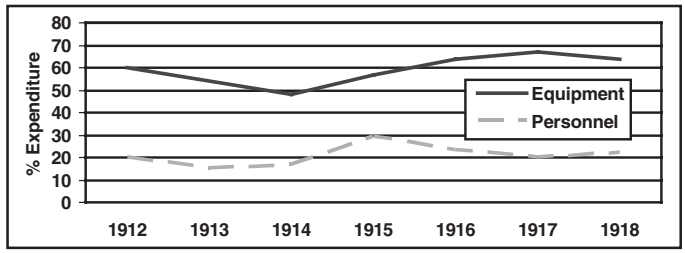

Figure 6. Air Service Expenditure by Category

Sustaining Airpower: Influence of Logistics on RAF Doctrine

While some commentators have criticised the Allies for employing their significant economic and industrial capacity to support a military strategy built on brute force, the attritional nature of modern warfare and the pace of technological change allowed little choice in the matter.

the size of the frontline and the supporting reserves, consuming some 36 percent of the rearmament budget in the process (see Figure 7).

The result was a vast array of depots and maintenance units, specialising in storage, repair, salvage, and armament, that had no parallel in the Luftwaffe where the doctrine of a short war negated the need for investment on a similar scale. Thus, over a period of 20 years the home-based RAF had been transformed from what was largely a training organisation based around grass airfields and temporary accommodations to a permanent system of stations and maintenance units that would provide the fighting platform for both defensive and offensive action.

The impact of this change was deeper than might be imagined, as it touched on that most intangible of issues—ethos and culture. The station became not only the key element in the exercise of command and control, but also a microcosm of the Service itself. In this sense, the station occupied a very different position to the garrison, shore establishment, or dockyard. This was reflected, if nothing else, in the status and authority of the station commander enshrined in King's Regulations and the Air Force Act. While squadrons were the fighting arm, the majority of RAF personnel served on the strength of a station, undertaking the wide range of support activities needed to keep aircraft flying.

To shed some light on the differences between the Services it is interesting to note that in both 1918 and 1945, the RAF possessed more airfields and support units in the UK than frontline squadrons (see Figure 8). The same could certainly not be said about the number of ports versus warships or the number of garrisons versus regiments.

The Second World War

This massive investment in sustainability came into its own during the Battle of Britain. The disparity in approach to logistics issues between the respective air forces became clearer as the campaign progressed. Fighter Command maintained (if not enhanced) its frontline numbers during the battle, while the Luftwaffe declined in strength as availability fell and aircraft and pilot wastage rose beyond the supply of replacements.

Notwithstanding heavy losses (fighter wastage reached over 50 percent per month during 1940), RAF reserves continued to grow throughout the war. The average number of aircraft in storage awaiting issue to the Metropolitan Air Force rose steadily, reaching over 10,000 by 1944, where it remained until the end of the war (see Figure 9).[21]

While some commentators have criticised the Allies for employing their significant economic and industrial capacity to support a military strategy built on brute force, the attritional nature of modern warfare and the pace of technological change allowed little choice in the matter.[22] While it is true that the RAF and the United States Army Air Force relied on high production rates, an extensive supply system, and comprehensive support arrangements to compensate for high

operational wastage, it is also true that these resources were available as a result of careful and detailed planning, driven by what the First World War had demonstrated about sustainability and airpower. Both air forces had long recognised that warfare in an industrial age demanded supply on an industrial scale.

The closest parallel to Trenchard's *incessant offensive*, the combined bomber offensive was founded on a massive industrial effort and a world-wide training programme that produced sufficient heavy bombers and crews to maintain operations in the face of desperate attrition. During the course of the war, Bomber Command lost over 74,000 aircrew (either killed, wounded, or prisoners of war) and 12,330 aircraft to operational and nonoperational causes[23] against a frontline strength that reached 4,384 aircraft by May 1945. During the course of 1944, 12,295 heavy bombers were delivered to Bomber Command—3,285 repaired, and the remainder new production—a wastage rate of 950 percent.[24] [25]

The manufacture, modification, and repair of aircraft had, by 1943, become Britain's largest industrial operation.[26] From 1939 to 1945 over 131,000 aircraft were produced, compared to 55,000 in the First World War. However, the complexity and weight were a magnitude greater, as was the cost. In 1943 alone, expenditure on new production by the Ministry of Aircraft Production (MAP) totalled some £800M (equivalent to £83B at today's prices).[27] Total wartime expenditure on aircraft and related equipment exceeded £3,75M (£385B) while the capital cost expended in creating the necessary industrial capacity amounted to £350M (£36B). Overall, more than 36 percent of wartime defence expenditure (around 20 percent of the UK GDP) was committed to the RAF, of which some 40 to 50 percent comprised equipment costs.[28]

At its peak (in the summer of 1944), more than 3 million personnel were employed in aviation-related activities, including 1.7 million in MAP and over 1 million in uniform (see Figure 10). This compares to a total employment of 630,000 in the First World War. In fact, the remorseless consumption of labour by the RAF and the MAP soon became unsustainable and had to be scaled back in favour of the Army and other critical war industries.

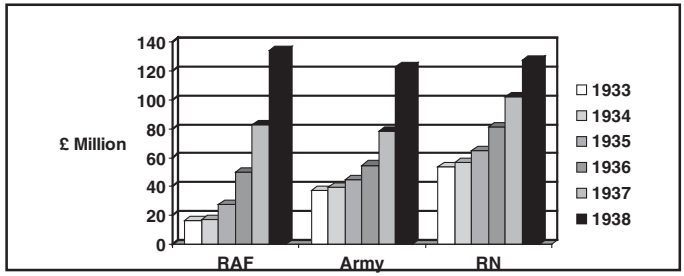

Figure 7. Comparison of Annual Defence Expenditure 1933-1938

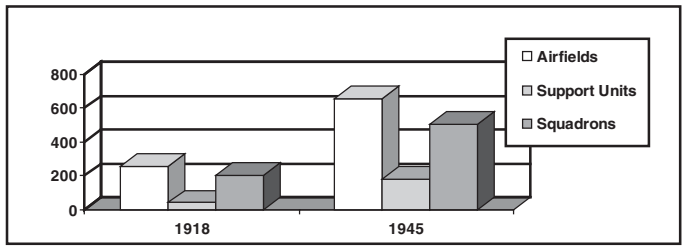

Figure 8. UK Airfields and Support Units

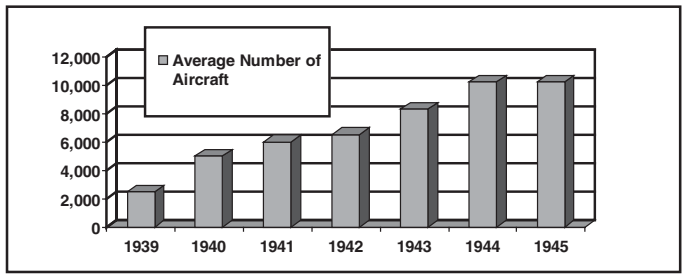

Figure 9. Aircraft in Storage 1939-1945

Sustaining Airpower: Influence of Logistics on RAF Doctrine

The early post-war years also saw a succession of studies and trials designed to determine optimum working patterns and organisational structures.

Nightly attacks by hundreds of heavy bombers against targets in Germany and Occupied Europe also demanded a sound and secure infrastructure. From 1939 to 1945, the airfield construction programme was Britain's largest civil engineering project since the building of the railways in the 19th century. A total of 444 new airfields were constructed in the UK at a cost of £200M (£20B) and employed over 300,000 men.[29] Approximately 1,800 airfields were constructed worldwide over the same period.[30] Each airfield consumed a vast range and quantity of resources, ranging from hardcore, concrete and bitumen for the runways, taxiways, dispersals and roads, to wood, bricks, and steel for the technical accommodation and hangars. Stations—and there were 59 distinct designs dependant on functional role[31]—also required dedicated utilities and waste disposal, as well as extensive storage facilities and domestic accommodation. In 1942 over £145M (£16B) was spent on works for the RAF compared to just £4M in 1935, at the start of the expansion programme. [32]

By the end of the war, the RAF frontline comprised some 500 squadrons and 9,250 aircraft.[33] The total inventory was in excess of 55,000 airframes with over 10,000 in store or in reserve in the UK alone, with a further 1,900 under or awaiting repair. New aircraft were being delivered at the rate of some 2,000 per month. As a result, the teeth to tail ratio was remarkably similar to that found nearly 25 years earlier—1 to 6 in 1945, and 1 to 8 in 1918 (see Figure 11).

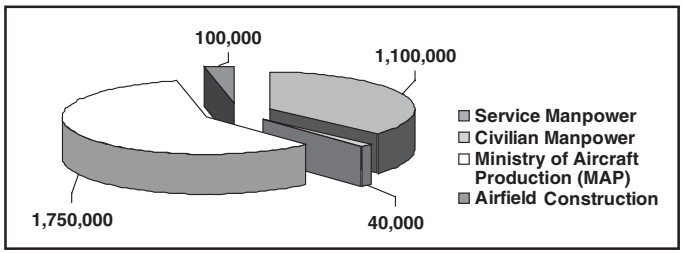

Figure 10. British Aviation Manpower July 1944

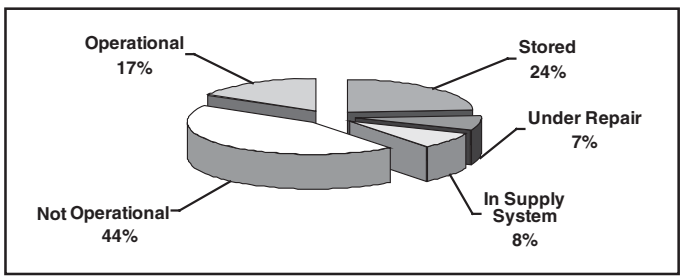

Figure 11. RAF Aircraft Dispositions May 1945

Post-War Organisational Models

While the scale of the effort expended on the RAF during the Second World War was impressive, every brick laid and ton of concrete poured, anchored the Service's future to its infrastructure. Demobilisation and substantial reductions in manpower and estate did not alter the emphasis on the station as the RAF's centre of gravity. The Cold War, and the decreasing importance of expeditionary operations, enshrined this perspective, assisted by further infrastructure investment to accommodate heavier and faster aircraft as well as new roles, such as nuclear deterrence.

The early post-war years also saw a succession of studies and trials designed to determine optimum working patterns and organisational structures. This work had commenced during the war with research into improving manpower utilisation and aircraft availability through *planned flying* and *planned servicing*.[34] The focus was very much about treating operational output as a mechanistic process that could be improved using work study methodologies.

A similar effort was expended on determining best practice in the deployment of station manpower and

appropriate station structures. An experimental station organisation was tested at RAF Tuddenham in 1946.[35] One of the aims was to relieve the station commander of a mass of administrative work. It was also hoped to weld station personnel into a single unit and thereby foster a good station loyalty and morale. A related study at RAF Binbrook also took place in 1946. It is perhaps the more famous of the two trials. From this latter study emerged the *standard* three-wing station structure (executive, technical, and flying) that has been the foundation of RAF station structures to this day.[36] The subsequent *Benson Experiment*, conducted in 1956, sought to address a number of detailed process and procedural issues largely related to personnel conditions and group cohesion.[37]

The effort put into these studies and related work on squadron structures and alternative models for the management of maintenance (centralised, autonomous and semi-autonomous), was tacit recognition that the station was central to how the RAF went about its business. They might also be seen as *legitimising* the role of sustainability in determining the organisation and management of the Service.

While the Cold War reigned, and with expeditionary warfare a remote prospect, there was little incentive to change structures and certainly no challenge to the station's primacy in the organisational hierarchy. Command of a station remained the aspiration of every ambitious officer and was widely seen as a critical test of an individual's ability and career potential. The station also loomed large in RAF culture, providing the social and domestic focus for the wider Service community. It is hardly surprising, therefore, that attempts to modify the basic station structure or to develop innovative administrative and operational arrangements, such as the Bentwaters/Woodbridge *Twin-Base Concept* in 1991, made little headway.

Expeditionary Warfare

RAF organisational structures and their associated processes continue to reflect the arrangements developed during the Second World War. Indeed, the emphasis on infrastructure, the heavy investment in equipment and the high ratio of support to combatant personnel have been defining characteristics of the Service for nearly 90 years.

Expeditionary warfare and network enabled capability may be about to shift this particular paradigm. The *End-to-End Logistic Study*,[38] now known as the Logistic Transformation Programme (LTP), and continuing work on station structures offer the prospect of a significant change in the way the RAF is organised. Expenditure on aviation logistic support and on the procurement of aviation and aviation-related equipment continues to represent a significant proportion of the defence budget. History teaches us that this is not an unprecedented position, but, while it may prove challenging to reduce substantially the cost of sustaining airpower, the way the frontline is supported will certainly alter in the next few years.

We will see fewer uniformed support staff with some functions no longer carried out at station level—and many no longer under the control of the station commander.

Expenditure on aviation logistic support and on the procurement of aviation and aviation-related equipment continues to represent a significant proportion of the defence budget. History teaches us that this is not an unprecedented position, but, while it may prove challenging to reduce substantially the cost of sustaining airpower, the way the frontline is supported will certainly alter in the next few years.

Sustaining Airpower: Influence of Logistics on RAF Doctrine

We must avoid the temptation of believing our predecessors to have been somehow less imaginative or more hidebound than we like to think we are. The logistics systems deployed by the RAF in both World Wars, and throughout the Cold War, were more than effective—they were winning solutions. We should build on these successes while seeking better ways to meet today's needs. To my mind, caution and a degree of humility are called for rather than a relentless dash for the new and untested. Paradigms are rarely shifted overnight.

The four lines of maintenance and repair that have held good for over 50 years will disappear. The effect will be to dilute the status of the station in the overall organisation with a greater emphasis on force elements as the RAF's centre of gravity. We may therefore need to *unpick* the Binbrook model. The difficulty will be to sustain Service ethos while creating a more agile and adaptable organisation. The basic building block in the new construct may well be the squadron, if not the flight, rather than the station.

There is no doubt that the *brute force* approach to logistics is no longer viable. This approach is unaffordable, and does not provide the flexibility and responsiveness that network-centric warfare demands. The logistics problems faced in Iraq were less about quantity and quality, and more about availability. The continuing concern about the inability to track individual items, and the debate about *precision-guided* logistics, presage fundamental changes in the way that supply chains and logistics will be managed in the future.[39]

It is likely that we will gradually see a transition from a supply chain, built around a hierarchy of organisations, to a distributed network that can respond rapidly to changes in demand. The LTP echoes this approach although it does not (yet) offer the self-synchronisation needed to provide a *sense and respond* network.

We need to be cautious about what can be quickly achieved. After all, the RAF has toyed with serial number item tracking for at least 30 years. We also have a vast inventory, support processes and policies tied to legacy weapons systems. Much as we might wish to move from supporting platforms to supporting military effect, there is a limit to what can be done with our older assets.

Although I have stressed the distinguishing characteristics of aviation logistics, as compared to defence logistics in general, these differences are likely to diminish with time as all military equipment becomes more complex and support systems more sophisticated and interdependent.[40]

As warfare moves from the industrial age to the information age, we will inevitably see a change in the nature of logistics. Success will be measured by the adaptability of the support organisation rather than by its scale or scope. If nothing else, this threatens to transform the relationship between airpower and sustainability that has held sway for nearly 90 years.

But, however much we succeed in transforming our logistics processes, there will continue to be a tension between efficiency and effectiveness. A just-in-time philosophy built around a responsive and agile supply pipeline, a minimum deployment footprint, and extensive host nation support, may not always provide the resilience needed to sustain military capability.

A final word of warning, we must avoid the temptation of believing our predecessors to have been somehow less imaginative or more hidebound than we like to think we are. The logistics systems deployed by the RAF in both World Wars, and throughout the Cold War, were more than effective—they were winning solutions. We should build on these successes while seeking better ways to meet

today's needs. To my mind, caution and a degree of humility are called for rather than a relentless dash for the new and untested. Paradigms are rarely *shifted* overnight.

Notes

1. Sir Frederick Sykes, *From Many Angles*, London, UK: Harrap & Co, 1942, 97.
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10. National Archives/Public Record Office, AIR 1/686/21/13/2252, United Kingdom, contains a detailed breakdown of this analysis.
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39. *Aviation Week & Space Technology*, 12 Jan 2004, 45-46.
40. *Ibid.* The US M-1 Abrams tank has been described as "the world's fastest strategically immobile tank" because of its huge logistics tail.

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Generating Opportunity from Uncertainty

Introduction

Uncertainty both pervades the current international security environment and obstructs our view of how this environment will evolve.

—David C. Gompert [1]

While the world displays growing strategic uncertainty, a potential disconnect has developed between military and business leaders on the treatment of uncertainty. The common view held today in business is reflected in the observation that organizations "abhor uncertainty."[2] Meanwhile, the military has long faced uncertainty in the conduct of war.[3] As a result, military leaders act on the best information available about how a human enemy will reason or react. Military theorists are familiar with uncertainty from Clausewitz's term *fog* that refers to the general unreliability of information.[4]

Uncertainty relates to both the existing *state* of an organization's environment and future *outcomes*. Uncertainty about the existing state an organization finds itself relates to vague, fragmented, unstructured, and the contradictory nature of information at a given time. Uncertainty surrounding future outcomes results from an imperfect understanding of variables and their relationship to enable predicting future outcomes. For both state or outcome uncertainty, at least some uncertainty remains irreducible in that not all available information or possible outcomes can be known with certainty.

Uncertainty tolerance is an important aspect of personal and organizational resilience. Similar to the relationship between a person's stress and performance, or teams and conflict, it is likely that organizations perform best under conditions with some uncertainty.[5] After it is introduced, uncertainty likely stimulates

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organizations to take actions to become more robust. Uncertainty creates stress by limiting the usefulness of interpreting information with current procedures.[6] The response to this stress is adaptive behaviors to increase uncertainty tolerance. However, uncertainty can progress beyond levels that can be effectively managed.

Well-led organizations display greater uncertainty tolerance and are more adept at operating under uncertainty. They will have an advantage over organizations less tolerant of uncertainty. While uncertainty can reach a point where it exceeds an organization's tolerance and performance falls, the performance of organizations at the same level of uncertainty varies based on their tolerance to it and impact the effectiveness of organizational responses to a changing environment. The goal therefore is not to eliminate uncertainty, but to benefit from it through sound leadership. If differences in operating under uncertainty exist between organizations, a competitor with greater uncertainty tolerance will benefit from some uncertainty. Therefore, an obvious military strategy is to reduce the amount of fog (or uncertainty) you face about a situation's state or likely outcomes relative to an adversary. Leaders that use uncertainty to create opportunities display the most advanced system of thinking about strategy.[7] The goal is to change the rules of the game or get inside a competitor's decision cycle, so leaders and their organizations can achieve success.[8]

The military's history of facing an uncertain strategic environment provides examples and guidelines for facing and taking advantage of uncertainty. Outlining how leaders can better respond and prepare their organizations for uncertainty is the goal of this article. The article proceeds by first outlining an historical example, and then using it to develop responses leaders can take to increase their organization's ability to handle uncertainty. Before concluding with a discussion, the performance implications of uncertainty tolerance are considered.

Historical Example

An early example of the impact of uncertainty on a military organization comes from a Greek mercenary force of 10,000 hoplites (infantry equipped with shields and spears) that served and traveled into Persia with Cyrus, a contestant for the throne of the Persian empire around 401 BCE.[9] Following the battle of Cunaxa, where Cyrus was killed by the forces of his older brother Antaxerxes II, the real journey of the Greeks began, as their worst fears were realized with the death of their sponsor.[10] The Greeks were in hostile territory over 1,000 miles from home.[11] Additionally, the promise of wealth that initially motivated them disappeared with the death of Cyrus. Further, the Greek hoplites had already traveled and plundered the most direct route home—largely a flat plain that provided an advantage to the Persian cavalry.[12] Following the execution and capture of their leaders, the Greek mercenaries banded together, formed a council, and chose the uncertainty of going north into the uncharted territory of the Carduchian mountains.[13]

Following the decision to go north, the Greeks adjusted their tactics and invested to improve their capabilities as a military force. The Greeks first improvised their formation to form a hollow square surrounded by hoplites to protect their baggage train and camp followers.[14] This change alone did not offer protection from Persian archers and slings, as these light troops could engage the Greeks from long range and disperse before they could be engaged in close combat. Therefore, the Greeks scavenged for horses to field cavalry, and invested in slings and bonuses for people willing to volunteer as slingers.[15] The Greek slingers used lead, an improvement over the stones used by Persian slingers, providing the Greeks a greater effective range.[16]

The retreat north welded the different Greek divisions together with the common purpose of returning home. As the Greek force entered the mountains, the Persian army stopped its pursuit because few Greeks were expected to survive the oncoming winter. Additionally, the Greeks had no maps and the local inhabitants greeted them with hostility. Constant attacks threatened to separate the Greek force as it stretched out along mountain trails. The need for information resulted in sending scouting parties to find routes and places to make camp and to search for hostile activity. The need for information also led the Greeks to take and question local prisoners. At one point, when faced by a dead end guarded by hostile forces, two prisoners were questioned about alternate routes.[17] When the first denied any alternative in the face of threats, his throat was cut in front of the other. The remaining prisoner provided the Greeks another route through the mountains, yet Greek losses in these few days were comparable to the three months they spent in Persia.[18]

Sighting the Black Sea offered the Greeks a false promise of the familiar and resulted in a splintering of the remaining 8,200 survivors into three groups.[19] The smaller groups were more easily harassed, and resulted in 1,000 Greek casualties in a single week.[20] Even when the mercenaries came upon Greek settlements along the sea, their reputation preceded them and the mercenaries were denied assistance. Not only were the Greek outposts along the Black Sea not Greece, but the mercenaries themselves were changed from their experience. The harried Greek mercenaries increasingly relied on superstition and ritual sacrifice to divine a way forward. Because they learned how to survive as soldiers, the journey of the Greeks ended similar to how it began—they became mercenaries in another fight against Persia.

The example of the Greek mercenaries and their response to uncertainty offers three lessons. First, organizations respond to uncertainty by investing in improving their capabilities. Second, change that coincides with uncertainty affects both organizations and their environment. Third, even in a changed environment improved organization capabilities remain valuable. How these lessons relate to uncertainty today is discussed next.

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Responses to Uncertainty

Clausewitz identified two responses for managing uncertainty—intellect and courage.[21] However, the example of Greek mercenaries suggests additional

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The creation of standard bodies of knowledge also encourages specialization. Specialization decreases an organization's variance by improving identification of possible outcomes and understanding of cause and effect, or increasing its uncertainty tolerance.

opportunities. First, the degree of uncertainty that can be managed will be directly and indirectly influenced by a leader's actions. The Persian attempt to disband the Greeks by removing their generals was overcome by the Greeks forming a council that decentralized decisionmaking. Second, the Greeks took action to increase uncertainty tolerance. In response to environmental change, the Greeks used resources on hand to field slingers and cavalry to keep their forces competitive. Translating the Greeks actions to today offers two strategies for increasing uncertainty tolerance—learning and resource investment.

Learning

Learning reduces variation in performance and may involve one of the most important ways to reduce uncertainty.[22] Organizations continuously learn by gaining knowledge about their capabilities and environment, and learning faster than competitors provides an advantage. For example, the Greeks used scouts and took additional actions to learn more about their environment. Additionally, organizations can learn simply by exercising capabilities.[23] The Greeks adapted a hollow square formation and developed cavalry to protect their movement from Persian attack. All organizations exhibit a capability to learn. Experience increases the organization's ability to effectively handle the amount of uncertainty.

Knowledge is dynamic in the sense that the best source for gaining additional knowledge is reflecting on what someone already knows. The fact that knowledge builds on itself causes people with similar experience to develop their own language for discussing ideas. As a result, organizations under similar conditions evolve in similar ways as the demands of an organization's environment lead to the exercise of similar capabilities. The result is for professions to display a common body of knowledge.

The creation of standard bodies of knowledge also encourages specialization.[24] Specialization decreases an organization's variance by improving identification of possible outcomes and understanding of cause and effect, or increasing its uncertainty tolerance. Specialization can also increase variance between organizations by enabling an organization to develop a protective niche where it has a better understanding of the potential outcomes for change. The military equivalent to specialization is combined arms—the Greeks expanding their infantry resources to also include cavalry and slingers with ranged attack. Leaders will give their organizations the best ability to tolerate uncertainty by increasing the diversity of specialization. When uncertainty occurs where an organization has specialized resources, it will be better positioned to respond to change.

Resource Investment

Leaders can develop an expectation for change by investing to improve an organization's resources. Uncertainty helps justify higher investment by providing organizations appropriate resources to respond to competitors.[25] The ability

of organizations to benefit from uncertainty varies because of differences in learning and level of resource investment.

Resource investment likely facilitates innovation by enabling organizations to act in accordance with the demands of an uncertain environment.[26] For example, the environment the Greeks faced led to their investment in lead shot that gave their slingers a relative advantage against the Persians. Sustained investment develops valuable resources that build an organization's knowledge.[27] Specifically, an organization's investment decisions and experience develop knowledge and an ability to recognize and exploit information.

As capability grows, improved information results in an organization having greater understanding of its environment and for new resource combinations that result in innovation. Innovativeness enables organizations to meet the demands of an uncertain environment by enabling sporadic or even continuous adjustments to organization resources and products.[28] Developed resources help predict the probability of success under uncertain conditions and provide resources that can be applied to other uses. For example, the Greek hoplites fielded cavalry from horses and soldiers already within their group or from available resources that improved their performance. As such, knowledge and resources have greater utility in uncertain environments because they build uncertainty tolerance and allow organizations to adapt and take advantage of opportunities.

However, resource investment offers diminishing returns because uncertainty persists in the face of efforts to reduce it. Continuing change may alter previous relationships resulting in a mismatch between an organization's actions and its environment. Still, organizations should continue to invest in new capabilities. Foremost, investments can introduce new resources and pave the way for organizational change. For example, the Greeks' survival was aided by combined arms or fielding cavalry and slingers that complemented their core hoplite infantry. Additionally, success in using new capabilities may depend on interactions with other capabilities or provide an organization the ability to surge or respond to challenges.

Resource investment offers diminishing returns because uncertainty persists in the face of efforts to reduce it. Continuing change may alter previous relationships resulting in a mismatch between an organization's actions and its environment. Still, organizations should continue to invest in new capabilities.

Even in the face of diminishing returns, continued investment still offers relative advantages. First, organizations may not represent an equal threat to one another or have the same uncertainty tolerance. Leaders need to recognize they only need better information than competitors, not perfect information, to have an advantage. Second, unsuccessful investments are still worthwhile because knowledge generated will often be useful elsewhere in an organization or in other contexts.[29] In other words, developed resources continue to have a residual value that provides a safety net for continued investment. Finally, uncertain environments may magnify the perceived value of developed capabilities. For example, the experience of the Greek mercenary force in retreat from Persia only made them more valuable in the next conflict.

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Even though luck plays a role, organizations with greater knowledge should enjoy luck more often. Differences in uncertainty tolerance should help explain differences in organizational performance. When uncertainty begins to exceed an organization's ability to easily respond, small differences in the ability of organizations to cope with uncertainty will make a difference. In uncertain environments, the ability to make more informed decisions rapidly will provide an advantage over competitors.

Uncertainty and Performance

Leaders need to consider the impact uncertainty will likely have on their organization's performance. The initial impact of uncertainty will be reduced performance until adjustments are made. As an organization adapts, tolerance of uncertainty increases and performance should improve. For example, the Greek hoplites were at a disadvantage to Persian slingers until they adjusted their tactics. Organizations take action to reduce uncertainty by improving available information. As swift moving environments challenge beliefs, successful organizations accept the need to have an ability to adjust by building in the expectation for change.[30] For example, the uncertain environment confronting the Greek mercenaries served to clarify their goals and strengthen their organization.

When uncertainty is accepted performance improves. It provides purpose and efforts to increase knowledge and make better choices. For example, it has been observed that people learn to respond to chance in proportion to their observations, or try to maximize the number of times they are right by alternating their predictions instead of making the same bet every time.[31] From the perspective of organizations with better information, knowledge should translate into making better decisions based on a superior understanding of likely outcomes. A complication is that people tend to have difficulty recognizing when information is sufficient, past experience no longer serves a useful guide, or there is too much information.[32] Too much information can result in worse decisions because irrelevant information simply serves as a distraction.

If the environment continues to shift and no reliable information on which to base decisions is available, performance will decline rapidly. The only condition consistently leading to success other than superior information is luck.[33] As the number of potential outcomes expands, small changes can have a big impact and it may be difficult to know what has changed. The implication is that uncertainty—even with knowledge—can reach a point where continued success will depend on luck.[34]

Even though luck plays a role, organizations with greater knowledge should enjoy luck more often. Differences in uncertainty tolerance should help explain differences in organizational performance. When uncertainty begins to exceed an organization's ability to easily respond, small differences in the ability of organizations to cope with uncertainty will make a difference. In uncertain environments, the ability to make more informed decisions rapidly will provide an advantage over competitors.

Increased luck may relate to leaders knowing their information is better. Differences in experience and accumulated knowledge result in different perceptions of opportunity for the same situation. For example, it has been observed that uncertain prospects are viewed as less attractive when they are also considered by someone else that is perceived to be more knowledgeable.[35] Though leaders may not know a complete set of outcomes, they may be able to rule out *bad* choices or identify better decisions than rivals.

Conclusion

Decisions are made despite uncertainty—even taking no action is a decision. Better decisions are likely to be made under conditions where an organization can tolerate and manage greater amounts of uncertainty. As a result, the impact of uncertainty on organizations is more complex than has generally been recognized. Leaders can make their organization's tolerance for uncertainty more robust. While its introduction may be unpleasant, uncertainty likely leads to a closer examination of the environment and an organization's role in it. This should contribute to expanding an organization's ability to make decisions based on identified potential outcomes, and improved decisionmaking from better information should contribute to higher performance. Doing better than competitors depends on higher tolerance of ambiguity from learning and capability development that ensures better information than its rivals on a range of topics. As such, leaders should ensure their organization avoids specializing in too few areas.

Leaders can apply several lessons learned from the observations and arguments explored here. First, attempting something is the first step toward managing uncertainty, as an outcome is certain only when no attempt is made. For example, instilling the belief that something is impossible will likely preclude any achievement inconsistent with that belief. As a result, it is on the margins where leaders make the biggest difference. If things went according to plan, we would not need leaders. At the same time, greater demands and discretion under conditions of uncertainty increase the responsibility for leaders to act appropriately—integrity first.

Leaders also need to dedicate time to figuring out what they want to achieve and how to get there. The challenge is to achieve "transformation that is revolutionary in result and evolutionary in execution."[36] The spoils will go to leaders of organizations that manage uncertainty to favorable outcomes by making their own luck along the way. There is no *one* way to be successful. Leaders should seek to employ workable solutions that can be adjusted as additional information becomes available, rather than waiting for perfect solutions that risk irrelevance.

Leaders can make their organization's tolerance for uncertainty more robust. While its introduction may be unpleasant, uncertainty likely leads to a closer examination of the environment and an organization's role in it. This should contribute to expanding an organization's ability to make decisions based on identified potential outcomes, and improved decisionmaking from better information should contribute to higher performance.

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Lieutenant Colonel Andrew Hunt, USAF

Air Force Logistics Readiness Officers: How to Be Successful in a Joint Environment

From July 2007 to June 2008, I had the privilege of attending the United States Marine Corps Command and Staff College. For nearly a year, I studied the Marines' (and the other Services represented in my conference group) doctrine, history, and current tactics, techniques, and procedures. During that same year, I often found myself at the *pointed end* of some pretty good verbal jabs from my leatherneck friends. What became apparent to me was that the current fight does not lend itself to Air Force success stories. Instead of touting the efforts of our expeditionary combat support personnel, the Air Force has been forced to go on the defensive. The Secretary of Defense actively called-out the Air Force to do more in supporting the Global War on Terror (his comments were directed almost exclusively at the rated community). Where the Air Force has succeeded is in providing top-notch logistics support to our Joint comrades. Many sister Service members recognize the efforts of the Air Force logistics readiness community in the deployed environment. They see us on convoys, sitting in Joint operations centers, and often venturing outside the wire. Even though Air Force logisticians are viewed favorably in the Joint environment, there are certain steps logistics readiness officers (LROs) can take to ensure that they command the respect they deserve from their peers in the Army and Marine Corps. This short article addresses five keys to LRO success in a Joint environment.

First, be smart on Air Force Doctrine (and not just the 2-4 series). In the other Services (except for the Navy, where doctrine does not exist), doctrine is not a buzzword or a shiny new toy. Doctrine is a way of life. Marine Corps and Army officers know what their branch and their Service are supposed to do. In fact, most of those officers know what the other Services are supposed to do, too. Sometimes they know our doctrine better than we do. That's embarrassing.

It's going to take some time for the Air Force to embrace doctrine the way the Army and Marine Corps do, but it's got to happen. Doctrine has to be read,

Logistics Readiness Officers: How to be Successful in a Joint Environment

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understood, and implemented by all airmen. Being knowledgeable about the Air Force's capabilities and core doctrine statements will go a long way to earning much needed credibility.

The second key to success in a Joint environment is to possess a working knowledge of the tactics, techniques, and procedures, as well as the tables of equipment of the forces you are supporting. Understanding concepts of maneuver warfare, rates of advance, and rates of consumption by unit size will make any LRO a more valuable commodity. Logistics support of ground forces is, in my opinion, much more complex than supporting flying units from a fixed location. One of the best ways to get up to speed on this kind of information is to build and maintain a personal smartbook. There is a great deal of excellent information available through open sources; however, the best source of sister Service information will come from logistics professionals in that service. Make contacts and request briefings, slides, background papers, and anything that deals with combat support and combat service support. A slide show on the composition and airlifting of the Army's brigade combat team or a white paper on the Joint task force-port opening capability is out there if one knows where to look. The key is to keep the book up-to-date. As quickly as things change in today's world, last week's briefing may just be old news.

Third, don't feel like you have to apologize for how the Air Force does business. There are things you just can't do anything about. You can't control the length of our air expeditionary force deployments—don't be ashamed that you're only there 6 months when others are there for a year. That being said, be mindful of the sacrifices your comrades in the other Services are making. While 365-day taskings for LROs are on the rise, they have been the norm for the Army since this struggle kicked off. Be ready to correct perceptions that are flat-out wrong. Some folks think that the Air Force won't deploy anywhere there isn't a five-star hotel or a Starbucks. Show them the Joint manning document from the forward operating bases in the area of responsibility, highlighting where our airmen are. They might be surprised. This isn't to say a little self-deprecation isn't warranted now and again. Being able to poke fun at the Air Force will endear you to your Joint peers. Be ready, though, to stand up for what the Air Force brings to the fight. Remind folks that for the last 50 years, ground forces have enjoyed the luxury of not having to worry about aerial interdiction from enemy air forces.

You also can't do anything about how the Air Force viewed physical training (PT) in the past. Many of your Joint colleagues perceive the Air Force as being soft, a by-product of the much-maligned (and probably rightly so) cycle-ergonometry test. Run with them, ruck march with them, and that perception will start to fade. PT is slowly—very slowly—becoming part of our culture. As with doctrine, the Army and Marines are way ahead of us. There's work to be done, but the Air Force is on the right path.

The fourth key to success is to demonstrate your expertise. The quickest way to lose credibility in a Joint environment is to show up unsure of how to do your job.

That said, a learning curve is inherent. The challenge is to make that curve shallow and short in duration. Make contact with the LRO you're replacing and find out what kind of things you can do prior to deploying (such as getting a Global Transportation Network account). The quicker an LRO can insert him or herself into the fray and demonstrate competence, the better. Unfortunately, the LRO concept has made this key a difficult one to accomplish. Simply put, the depth of knowledge is different now than under the old 21S/T/G construct. Your Joint peers don't care. They expect you to know what you're doing 100 percent of the time. To them, you are the expert in your field.

The fifth and final key may seem superfluous, but it's not. LROs need to be well-read. In dealing with the officers from the other Services, you will find that they are, as a whole, very well-read and very articulate. This is a result of the importance that the Army and Marine Corps place on their reading lists and internal professional military education programs. It is a rarity to find a senior company grade officer or field grade officer in those branches that isn't versed on military history or current events. During my year at Quantico, I was blown away at the breadth of reading that my classmates had done. They actually read from their Commandant's reading list, and it pays dividends. Pick up a book by Thomas Barnett or Thomas Friedman, or fall back to a classic—*On War* by Clausewitz.

LROs have proven to be highly sought after individuals in today's Joint environment. We have demonstrated the ability to undertake various tasks and complete them in exemplary fashion. In fact, we've done so well, that we've become victims of our own success. Our 365-day taskings continue to increase while our personnel numbers stay the same or are reduced. Arguably, the LRO is the most visible and tangible link between the Air Force and the current fight against terrorism. Our Joint commitment will not diminish, nor will the expectations placed on us by our Joint colleagues. Take the steps necessary to show them that we deserve their respect and confidence.

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Colonel Donald A. Van Patten, USAF

Transforming the Aircraft Inspection Process

Introduction

To everything there is a season, a time for every purpose under heaven; … a time to break down, and a time to build up; … a time to keep, and a time to throw away; … a time to keep silence, and a time to speak; … a time of war, and a time of peace.[1]

—Ecclesiastes 3:1-8

The next 5 years promise to bring significant changes to the Air Force's current operating environment. This change is prompted by several budget initiatives to provide funds for vital programs that include recapitalizing the growing inventory of aging aircraft. Some of these initiatives target manpower billets in specific areas across the active, reserve, and National Guard forces with a projected goal of reducing full-time equivalent positions by approximately 40,000.[2] One initiative, released as Programmed Budget Decision (PBD) 716, directs the offsets to be fully executed by the end of fiscal year (FY) 2011 across most Air Force specialty codes (AFSCs) in order to minimize huge losses within a few areas. Within the past year, the period to complete the offsets has been accelerated to the end of FY09. PBD 716's impact on aircraft maintenance is to reduce aircraft inspection manpower by 402 billets—a significant decrease in maintenance capability.[3]

The Air Force's plan to reduce the inspection manpower focuses on regionalizing inspection centers for select aircraft types. Although the depot-level overhaul locations would remain unchanged, this plan would eliminate the base-level inspection docks by flying the aircraft to regional sites for their incremental hourly and periodic maintenance inspections.[4]

Transforming the Aircraft Inspection Process

The Air Force cannot increase aircraft availability and decrease operating costs without revamping the current inspection process.

In addition to the manpower reductions, the Air Force has begun efforts to improve aircraft availability and decrease cost. Faced with decreasing budgets, Air Force leadership established goals to increase aircraft availability by 20 percent and reduce costs by 10 percent.[5] Known as the Aircraft Availability Improvement Program (AAIP), all levels of aircraft sustainment have been directed to develop efficiency initiatives to achieve the PBD goals.[6]

In order to achieve the projected PBD 716 manpower savings of $23.4M over the Future Year Defense Plan (FYDP), there appear to be three viable options. The first option would be to yield the manpower positions while retaining the phase and isochronal inspection docks at their current base-level locations.[7] A second option would be to fully comply with the PBD and regionalize select inspection activities. The last option would be to develop a hybrid alternative—sending aircraft to the regional facilities for heavy inspections, but performing the light checks or minor inspections at the base.

This article analyzes these three options against the goals to increase aircraft availability by 20 percent, while decreasing cost by 10 percent. Additionally, it examines a third impact of these options on a unit's ability to control its success or destiny with respect to mission requirements. As part of the analysis, this study also investigates the theory of reliability-centered maintenance and analyzes its applicability to the inspection options.

Impetus for Change

The Air Force cannot increase aircraft availability and decrease operating costs without revamping the current inspection process. The first of several reasons for change is that the average age of our aircraft today is almost a quarter of a century (23.5 years) and has grown steadily over the past 3 decades. In 1967, the entire fleet's average age was only 8.5 years.[8] This equates to a 176 percent increase in fleet age over the 40-year period. Although the Air Force has started receiving the F-22, the average age of the Air Force's main fighter fleet is still over 20 years. This fact is not insignificant. Because the fleet has become geriatric, it is now susceptible to the normal problems that begin to surface with older airframes. For example, wiring has become a top driver for the F-15C/D. The insulation on the Kapton wiring used widely throughout the fighter aircraft has become brittle and cracked, resulting in an increasing number of electrical shorts and fires. The KC-135 has experienced peeling with its internal fuel tank coatings, leading to contaminated fuel systems and filters.[9] These age-related problems will continue to drive additional aircraft inspections, which in turn, will increase the amount of time the aircraft will not be available for flying.

The second drive for change is increased downtime for the aircraft fleets due to the increased inspections and other maintenance-related aging factors. Over the past 15 years, the amount of aircraft downtime per flying hour has increased and is reflected in the Air Force's maintenance man-hour per flying hour (MMH/FH) ratio

metric. For the entire Air Force fleet, this ratio increased 61 percent between FY91 and FY05 (see Figure 1).[10]

This is significant because the Air Force retired some of its oldest fleets of F-4 and F-111 aircraft during this same period without any major impact on the MMH/FH metric. For the aircraft maintenance community, this increase in workload, even with a newer total fleet, is monumental.

Additionally, the size of Air Force budgets has continued to slow at a disconcerting pace over the past several years. Based on current projected budget programs, the FY11 budget will be only 16 percent larger than the FY06 budget—a significant spending departure compared to the previous 6-year period of FY01 to FY06, when the budget grew nearly 44 percent.[11] Due to decreasing budget dollars, the Air Force will be forced to stretch recapitalization plans for replacement aircraft and need to retain older aircraft longer than originally planned to provide the required combat capability.

A fourth impetus for change is the increase in operating costs. Given the volatility of fuel prices, personnel pay and benefit expenditures, and other operating factors that comprise the Air Force total ownership costs (AFTOC), this important sustainment factor promises to rise faster than planned for in the budget requests through FY11.[12] The cost to operate an average aircraft in FY96 was just over $3M. In FY05, the same cost reached nearly $5.5M, an 83 percent increase.[13] This makes the stated AAIP goals even more challenging to achieve.

The last reason for change is the track record of legislative involvement. During the last 4 fiscal years (FY03-FY06), Congress prevented the Air Force from retiring aircraft deemed too costly to operate from the B-52, C-5, C-130E/H, F-117, and KC-135 fleets. As of October 2005, the number of aircraft congressionally restricted

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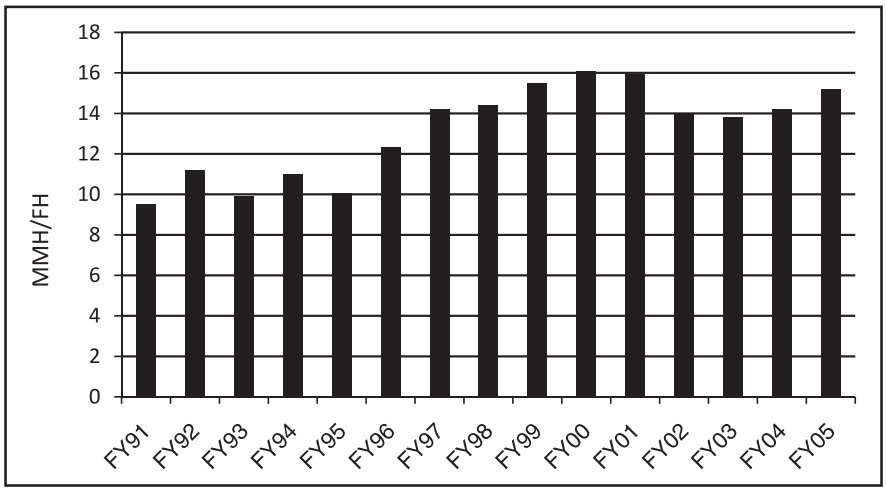

Figure 1. Total Air Force Maintenance Man-Hours per Flying Hour, FY91–FY05

from retirement had grown to a total of 104, creating a burden on critical budget dollars.[14] This well intentioned legislation has forced the Air Force to divert shrinking funds from other vital programs to sustain these geriatric weapons systems.

Analysis Criteria and Inspection Types

The three proposed options will be evaluated against three criteria: aircraft availability, maintenance operating costs, and unit control. Because having aircraft available for combat and training is a vital prerequisite to enable a unit to accomplish its wartime mission, the Air Force constantly evaluates the aircraft availability of its fleets to identify causes of negative trends.

The types of inspections discussed in this article are limited to the phase and isochronal inspections. The phase-type inspection is determined strictly by the number of operating or flying hours. If an inspection is due at 200 hour intervals, then the aircraft must be inspected at this point before it can be flown further. Aircraft that begin and end their sorties at the same location—such as fighter aircraft—normally operate on the hourly phase inspection concept. Isochronal inspections are based on a specified number of calendar days. Isochronal is a Greek word that means to occur in regular intervals of time.[15] The isochronal intervals are derived from an average number of flying hours that would be accumulated in the interval without degrading safety. The isochronal inspection concept is ideal for aircraft like tankers or airlifters that may fly multiple sorties away from home station. In conjunction with military representatives, the original equipment manufacturers (OEMs) determine the inspection type and intervals during the aircraft's initial operational test and evaluation stage. These types and intervals normally serve the aircraft with minimal change up to retirement.

To sufficiently analyze the data, two aircraft will be examined. Due to their significant numbers and the availability of research data, the phase-interval type F-15C/D fighter aircraft and the isochronal-interval type KC-135 tanker aircraft were selected for this study.

The three proposed options will be evaluated against three criteria: aircraft availability, maintenance operating costs, and unit control. Because having aircraft available for combat and training is a vital prerequisite to enable a unit to accomplish its wartime mission, the Air Force constantly evaluates the aircraft availability of its fleets to identify causes of negative trends. Aircraft availability measures the ratio of time a unit possessed aircraft is mission capable (MC) or mission-ready against the total time of possession by all organizations.[16] The formula used to calculate this rate is as follows:

Availability Rate = (MC Hours/Total Possessed Hours) x 100

An aircraft is considered in possession when it is under its assigned unit's control. For example, if the Air Force had a fleet of 100 aircraft, and in one day 20 aircraft were not MC and 10 aircraft were possessed by depot maintenance, the number of aircraft mission-ready or MC for this 24-hour period would be 70 percent. The calculation would be as shown below:

(70 MC unit possessed aircraft x 24 hours/100 unit and depot possessed aircraft x 24 hours) x 100

Of course, actual aircraft availability calculations are much more complex, as aircraft cycle through only a few of minutes or hours per day of not-mission-capable status before returning to MC status. As stated previously, the Air Force is striving to achieve a 20 percent improvement in availability across all its fleets of aircraft. A major way to impact availability rates would be to decrease the amount of time an aircraft is not mission capable and increase the amount of time an aircraft is unit-possessed and mission capable.

In light of PBD 716's emphasis on cost reduction, the second criterion analyzes the maintenance operating costs across the three options. As stated previously, the AFTOC data base captures the operating expenditures of unit-level consumption, intermediate maintenance, depot maintenance, contractor support, sustaining support, indirect support, and aircraft modifications from program element code (PEC) 3400 – Operations and Maintenance (O&M), and military and civilian pay from PEC 3500 – Pay and Allowances. The aircraft total operating cost is the total annual system costs of the two PECs divided by the total aircraft inventory (TAI).[17] The AFTOC costs most easily influenced at the unit, intermediate (regional), and depot levels are the maintenance and consumables expenditures. Minimizing these costs through a reanalysis of the OEM-developed phase and isochronal inspection construct would directly impact the inspection frequency and workforce size.

The last criterion for judging the effectiveness of the three options is the degree of control a unit retains over its phase and isochronal inspection program. Unit control has always been a foundational building block for maintaining a healthy fleet of aircraft. A flying organization plans and executes its flying-hour program with respect to its home station and deployment requirements, exercise and evaluation cycles, contingency rotations, and other local factors, including weather. The integral factor to achieving a successful flying-hour program is being able to control the flow and rate at which aircraft are inspected. The inspection process is the banking mechanism for building a savings account of flying-hour capability. It is commonplace for a unit to surge its inspection program periodically to respond to an externally-driven mission requirement that necessitates phase or isochronal inspection flexibility in order to accomplish the mission. The Chief of Staff of the Air Force (CSAF) recognized the importance of conjoined authority and responsibility when searching for a replacement to the objective wing structure that divided maintenance authority and responsibility between two groups. Under organizational structures where the maintenance group commander exercises both authority and responsibility for fleet health, aircraft performance has flourished.[18] Separating the phase and isochronal inspection capability from the direct control of the unit, as called for under PBD 716, partitions the necessary authority and responsibility to maintain fleet health in high tempo environments, especially combat and contingency operations. The most recent guidance in Air Force Instruction (AFI) 21-101 states that "Aircraft should not normally deploy with phase

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Transforming the Aircraft Inspection Process

The importance of reaccomplishing the FMECA analysis at appropriate intervals cannot be overstated; the cost efficiencies are realized by analyzing performance data on a recurring or iterative basis.

or isochronal inspections or engine time changes due immediately upon AOR (area of responsibility) arrival."[19] A unit's direct authority over its aircraft inspection program equates to being able to determine its own destiny or success, especially in combat and contingency operations. Pulling the phase or isochronal capability away from the unit has the strong potential to severely limit its flexibility to match flying requirements with fleet health maintenance.

The MSG-3 Inspection Construct

In the 1960s, an airline industry task force known as the Maintenance Steering Group (MSG) developed a new inspection program, known as MSG-1 (the first report published by the MSG), that produced substantial savings for the Boeing 747 (B747) over the DC-8.[20] Table 1 reflects the savings of the MSG approaches over the traditional approach.[21] In 1970, the Air Transport Association (ATA) led the airline industry in developing a second report (MSG-2).[22] This revised program converted MSG-1 into an inspection logic applicable to aircraft other than the B747.[23]

Interestingly, the preponderance of Air Force aircraft developed during this period utilized the MSG-2 preventive inspection logic. Although these early MSG preventive inspection processes produced huge savings, they were bottom-up approaches that focused on the failures of the individual items versus the effect of failures on the entire system. In addition, these early MSG approaches did not factor in operating performance data as the aircraft matured nor did they establish intervals for the preventive tasks.[24]

To overcome the MSG-1 and MSG-2 shortcomings, the reliability-centered maintenance (RCM) methodology was developed by United Airlines for the Department of Defense (DoD) in 1978. The ATA incorporated this new preventive maintenance program into the revised MSG-3 decision logic published in 1980.[25] The heart of RCM is the failure mode, effects, and criticality analysis (FMECA) which targets components and structures from a top-down systems approach.[26] The effectiveness of RCM is achieved through an *iterative* application of the FMECA throughout the weapons life cycle.[27] Additionally, a predetermined level of system performance and acceptable degradation are established during the analysis, as shown in Figure 2.[28]

The importance of reaccomplishing the FMECA analysis at appropriate intervals cannot be overstated; the cost efficiencies are realized by analyzing performance data on a recurring or iterative basis. Although the terms MSG-3 and RCM are often used synonymously, RCM is the methodology to determine failures and preventive maintenance actions. MSG-3 is the governmental- and industry-sanctioned application of RCM by way of a strong, integrated network of Federal Aviation Administration (FAA), airline operators, and original equipment manufacturer members. The MSG-3 construct allows the operator to adapt and change the inspection program to its particular operating requirements once reviewed and

approved by the FAA.[29] The preference to use the MSG-3 term in this article is intentional; MSG-3 connotes responsiveness and receptiveness to change. This is evident in the seven revisions made to MSG-3 from 1987 to 2005 to improve safety and preventive maintenance activities.[30]

Unfortunately, when the Secretary of Defense initiated sweeping reforms to the defense acquisition process in 1994, he also rescinded DoD's mandate to use RCM as well as the numerous Military Standards (MIL-STDs) that provided the methodology to accomplish the analysis. In its place, he mandated the services to rely on industry standards and best practices.[31] This action essentially orphaned legacy equipment, whose extended life cycles need the iterative engineering and operating analysis provided by RCM and the MIL-STDs. This statement is not intended to marginalize efforts by the weapon systems' engineers to improve the inspection continuum. However, constrained resources within Air Force

Type of Preventive Maintenance	Traditional Approach	MSG-1 & MSG-2 Approach
Structural inspections for 20K flying hours	4M man-hours for DC-8	66K man-hours for B747
Overhaul	339 items for DC-8	7 items for DC-10
Turbine engine overhaul	Scheduled	On-condition (cut DC-8 shop maintenance costs 50 percent)
*Traditional approach to maintenance held that the more frequently equipment was inspected and overhauled, the better it was protected against failure, thus resulting in numerous tasks.		

Table 1. MSG-1 and MSG-2 Savings

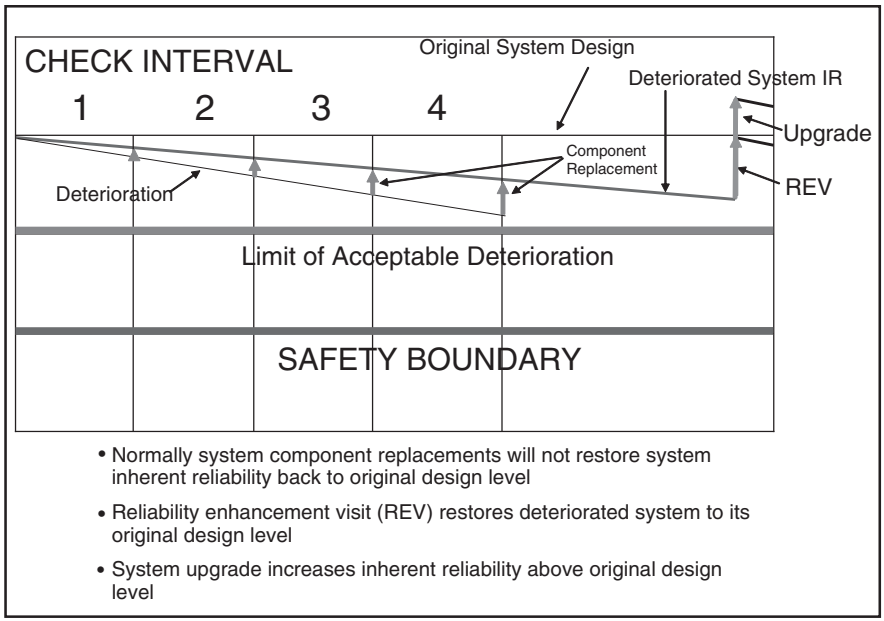

Figure 2. Predetermined Levels of System

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Transforming the Aircraft Inspection Process

The Air Force's older legacy aircraft now operate on an infantile preventive maintenance inspection concept primarily developed by the OEMs without having had the benefit of an MSG-3 end-to-end reevaluation of previous decades' systems and structural performance history.

Materiel Command (AFMC) have limited improvements to merely administrative-type changes to the OEM's initial inspection framework.[32]

Consequently, the Air Force's older legacy aircraft now operate on an infantile preventive maintenance inspection concept primarily developed by the OEMs without having had the benefit of an MSG-3 end-to-end reevaluation of previous decades' systems and structural performance history.

Analysis of Three Options

We must fundamentally change the culture of our Air Force so that all airmen understand their individual roles in improving their daily processes and eliminating things that don't add value to the mission.

—Secretary of the Air Force and Chief of Staff of the Air Force, 7 November 2005

To provide a meaningful analysis of the three options, it is important to examine these alternatives against actual aircraft that are potential candidates for the PBD 716 initiatives. The notional candidate fleets considered for regionalized inspections are the A-10, F-15, F-16, F-22, B-1, B-52, C-130, and KC-135 aircraft.[33] The analysis will be conducted using one aircraft from each inspection construct, the F-15C/D for phase inspections, and the KC-135 for the isochronal construct.

The F-15 inspection construct combines a series of light and medium hourly post flight (HPO) inspections and a major periodic inspection (PE) in a series of 200 flying-hour intervals. For a complete phase inspection cycle, the F-15 undergoes five HPOs and one PE to produce a total of 1,200 flying hours.[34] A complete cycle from the first HPO-1 to the PE entails 3,500 steps, 584 work cards, and 1,001 man-hours.[35] The average time the F-15 fleet was not mission capable (NMC) or not available for flying due to scheduled maintenance (phase inspections) per year during FY97 to FY06 was 2,169,296 hours out of 41,281,421 unit possessed hours, or 5.25 percent.[36] This equates to an average NMC time for phase inspections of 450.1 hours per aircraft per year. Additionally, during the same 10-year period, the availability rate averaged 67.0 percent and the total operating costs from the AFTOC data base averaged $3.676M per aircraft.[37]

The KC-135 uses an isochronal or calendar-based inspection cycle that is accomplished in 360 calendar days. The HPOs occur at day 30, 120, 180, 240 and 300.[38] Additionally, critical corrosion inspections occur at day 180 and 300, along with a mid-PE inspection at 600 flying hours and a major PE during the 300-day inspection.[39] Although the work cards do not provide a standardized timeframe to complete the steps, the average number of HPO and PE work cards and steps per year total 197 and 1,638 respectively. The average time the KC-135 fleet was NMC for scheduled isochronal maintenance during FY97 to FY06 was 2,878,133 hours

out of 3,821,265 unit possessed hours, or 75.32 percent.[40] Although this number seems unbelievable, and has been triple checked against the Multi-Echelon Resource and Logistics Information Network (MERLIN) database source, one possible reason for such a high scheduled maintenance rate may be due to the fact that the Air National Guard (ANG) possesses 196 airframes or nearly 40 percent of the total KC-135 fleet.[41] Since the ANG typically works only one shift per day, the doubled time to complete an inspection would contribute to the high scheduled maintenance rate when compared to the unit's time of possession. The average NMC time for isochronal inspections totaled 543.0 hours per aircraft per year during FY97–FY06 and produced an availability rate of 59.9 percent.[42] Additionally, the total operating costs from the AFTOC database averaged $4.184M per aircraft.[43]

Option 1 - Stay the Course

The first option is to continue accomplishing phase and isochronal inspections under the current organizational construct but with a reduction of 402 personnel, as called for in PBD 716. However, instead of the aircraft having its inspection performed at a regional facility, this option calls for completing the inspections at the possessing base. Evenly distributing the 402 manning losses across the Air Force's 73 active duty inspection docks in operation after the projected Base Realignment and Closure-2005 adjustments equates to a loss of 5.5, or 6 whole personnel per dock. As a result, the average F-15 phase dock would drop from 30 personnel to 24 and the average KC-135 isochronal dock from 35 to 29. This loss of manpower equates to an annual loss per inspection dock of 12,096 man-hours (6 personnel x 8 hours per day x 252 O&M work days per year). While it is difficult to measure the exact decrease in aircraft availability that would result under this option, a loss of 6 inspection personnel per F-15 dock would most likely extend the inspection of each aircraft by 1.5 days for HPO-1s, 2 days for HPO-2s, and 2.5 days for PEs. In a 1-year period, a single F-15 unit with 27 assigned aircraft would fall behind the current inspection production rate by 66 days, totaling 1,584 hours of aircraft nonavailability.[44] For the KC-135, the results would be similar. An annual inspection cycle with 35 personnel requires 40 days. Reducing the inspection dock down to 29 personnel would increase the time to complete the annual cycle to 48 days, causing a 12-aircraft unit to fall 96 days behind per year and lose 2,304 hours of aircraft availability. As is evident, this option would negatively impact aircraft availability due to the unit requiring more days to complete phase or isochronal inspections with less manpower. Consequently, the increase in aircraft nonavailability would drive a proportional decrease in possible sorties as well.

The first option is to continue accomplishing phase and isochronal inspections under the current organizational construct but with a reduction of 402 personnel, as called for in PBD 716.

Operating costs would obviously decrease with this option due to the PBD-driven reduction in manpower. As the PBD 716 document states, this reduction would provide an annual savings of $58,209 per person, or $23.4M for all 402 technicians.[45] At the unit level, the loss of 6 technicians would equate to a cost reduction of

Transforming the Aircraft Inspection Process

Aircraft availability stands to achieve significant increases under this option 2. One of the improvements in this plan is to standardize the work cards that direct the inspection activities.

$349,254, thereby positively impacting the cost criterion. However, all other costs would remain the same.

Unit control for this option, the greatest strength of the current inspection approach, remains unchanged. Although the unit will experience a lower aircraft availability rate, it will possess its assigned aircraft the same amount of days as compared to operations before PBD 716. Therefore, this option is judged as having a positive impact on this criterion.

Option 2 - Fully Employ PBD 716 Initiatives: Regionalize Inspections

Fully implementing PBD 716's initiatives, as notionally determined by the Air Staff, would require units within eight aircraft types—A-10, F-15, F-16, F-22, B-1, B-52, C-130, and KC-135—to accomplish all of their phase or isochronal inspections at regional inspection facilities while reducing the work force by 402 personnel. The concept calls for 10 regional stateside inspection facilities for the Combat Air Forces and four such facilities for the Mobility Air Forces, as shown in Figures 3 and 4.[46]

For overseas-assigned fleets, bases with similar fleets in the same geographical areas would combine their inspections at a single regional inspection site.

Aircraft availability stands to achieve significant increases under this option. One of the improvements in this plan is to standardize the work cards that direct the inspection activities. Currently, almost all aircraft technical order work cards are organized according to the AFSC-tasked inspection and aircraft zone, but not according to the most efficient flow of the inspection. This has led owning organizations to develop their own inspection flow sequencing based on their own requirements and preferences. This lack of standardization across the entire aircraft fleet causes lost time when inspection personnel are rotated among other bases and must learn the new unit's sequencing. Secondly, the locally-developed procedures are not updated promptly, if at all, to incorporate changes due to systems or structural improvements which represents lost efficiencies. Transitioning to a few regional inspection facilities affords the opportunity to conduct an Air Force Smart Operations 21 (AFSO21) study to mitigate these inefficiencies. AFSO21 is the Air Force's model to harness industry process efficiencies to improve operational support and eliminate nonvalue-added work using efficiency tools such as Lean, Six-Sigma, and Theory of Constraints.[47] These improvements would sequence the inspection activities for maximum efficiency and standardize the inspections across the entire fleet. Additionally, a robust training program would be developed to ensure maintenance inspectors fully understood their role in the flow sequencing and the rationale behind it. Early estimates proposed that each aircraft fleet's inspection flow time could be reduced by nearly 50 percent by incorporating these efficiencies.[48] Such reductions would enable the F-15 fleet to decrease scheduled maintenance downtime from a 10-year inspection average of 19 days to 12 days per year.[49] This could potentially add 7 additional days of availability per aircraft per year and up to 14 sorties annually. A similar improvement in isochronal inspections with the KC-135 fleet would decrease scheduled

inspection downtime from a 10-year average of 23 days to 14 days per year, leading to 9 additional days of availability and potentially 18 sorties per year.[50] For contingency operations, four additional deployable docks, two at each stateside regional site, would provide the capability to perform inspections at deployed sites. Aircraft availability under this second option would improve significantly. The rationale for such a prediction is based on the process efficiencies of restructuring the inspection flow for each aircraft.

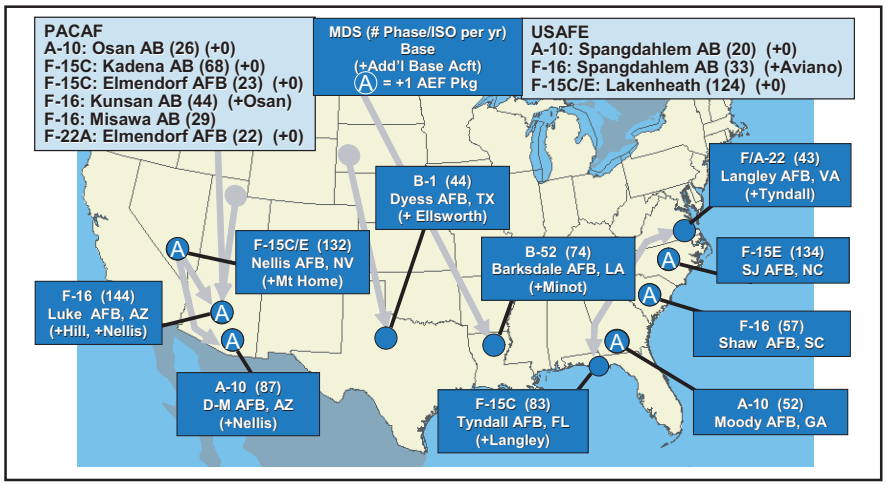

Figure 3. Option 2 Regional Inspection Concept—Combat Air Forces

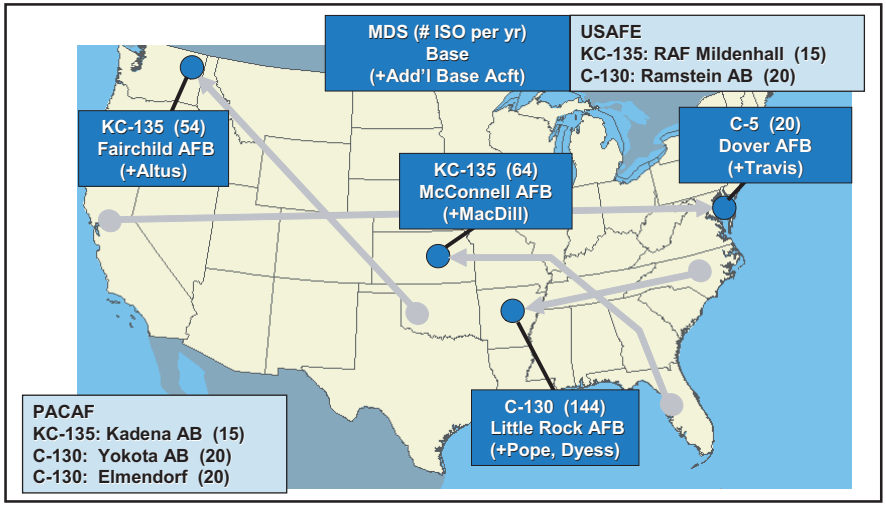

Figure 4. Option 2 Regional Inspection Concept—Mobility Air Forces

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Costs for this option would be similar to those of the first option—reduced primarily due to the loss of 402 personnel, providing a savings of $23.4M. However, these savings would be offset by onetime costs, as shown in Table 2.[51] Expenses to relocate the remaining 1,020 of 1,555 inspection personnel to their respective regional inspection centers, as well as fuel and travel costs incurred in ferrying the aircraft to and from the regional inspection facilities, would offset the savings. Achieving maximum benefits through an AFSO21 review would require assistance by experienced consultants. A projected $300K cost to implement the new concept at each of the 27 stateside and overseas regional sites would total approximately $8M; a cost well worth decreasing inspection flows by half.[52] An additional cost of $130K to relocate special equipment, hardware, and other assets per fleet would add $1.04M.[53] Despite these costs, a total projected annual savings of nearly $12M would accrue, excluding personnel relocation and aircraft ferry costs.

Inspection Dock Calculations		
	Before	**After***
A-10, F-15, F-16, F-22	50	29
B-1, B-52	7	4
KC-135	6	4
C-130	10	7
Total	73	44
* Based on 50 percent inspection flow reduction; does not take credit for BRAC		
Inspection Personnel Calculations		
Post-BRAC/Pre-Regional Personnel: 2,033		**After**
A-10, F-15, F-16, F-22	(30/dock x 29 docks) _ (30/dock x 6 AEF docks)	1,050
B-1, B-52	30/dock x 4 docks	120
KC-135		140
C-130		245
Total		1,555

Cost Calculations (in $M)							
1st FY = AFSO21 training/contractor and reorganization per MDS site = $0.30M							
2nd FY = Regionalization/relocate assets per MDS = $0.13M							
Aircraft	**Sites**	**FY07**	**FY08**	**FY09**	**FY10**	**FY11**	**Total**
F-16	5	$1.50	$0.13				$1.63
C-130	4	$1.20	$0.13				$1.33
A-10	4		$1.20	$0.13			$1.33
KC-135	4		$1.20	$0.13			$1.33
C-5 **	4			$0.30	$0.13		$0.43
F-15C/E	6			$1.80	$0.13		$1.93
B-52	1			$0.30	$0.13		$0.43
B-1	1				$0.30	$0.13	$0.43
F-22	2				$0.60	$0.13	$0.73
Total		$2.70	$2.66	$2.66	$1.29	$0.26	$9.57

Table 2. Option 2 Notional Implementation Costs

Unit control under this option would be the factor most significantly decreased. Current inspection operations allow the unit to determine their phase or isochronal production rate to meet internal and external flying requirements. This flexibility provides a critical buffer to balance mission requirements with maintenance capacity. Internally, a unit will increase or decrease the number of inspections based on the flying-hour program, sometimes phasing multiple aircraft simultaneously to yield short periods without any aircraft undergoing inspection. This approach has been a critical unit tool to support periods needed to upgrade pilots to four-ship aircraft flight lead prior to deployments or exercises. Additionally, units often preload their inspections to fly sortie surges. For example, an F-15C fighter squadron recently set a world record for the number of sorties during a 3-day surge—a feat not likely under a regional inspection concept.[54] In addition, external real-world mission requirements, such as short-notice contingency operations and deployments, would also be difficult to execute without being able to change inspection priorities or production rates. Prior to an air and space expeditionary force (AEF) rotation overseas, fighter units will typically increase or even surge their inspection production rate to amass enough inspections hours so that the unit doesn't need to accomplish any inspections immediately upon arriving in-theater. This surge enables the unit to have sufficient spare aircraft available with adequate remaining inspection hours.

Weather would also potentially impact the flow of aircraft inspections through a regional facility. Flying units normally attempt to maximize aircraft availability during the good months of summer flying—counterproductive to establishing a smooth fleet flow and maximizing capacity under the regional inspection dock concept. Consequently, during months of poor flying weather, the regional facilities would not have enough capacity to inspect the required number of aircraft. The regional inspection construct would require a highly responsive scheduling function in order to provide the same degree of flexibility. Finally, with inspection docks located miles away rather than just off the flight line, opportunities to cannibalize critical parts to generate sorties would be lost.

This option would improve the flow days through an efficiency study, standardized inspection technical orders, efficiently sequenced actions, and a highly skilled and trained work force. These positives would be offset by the other factors that would restrict flexibility at the unit level. The unit's ability to prepare for AEF commitments, sortie surges, and weather-driven issues, as well as respond to no-notice contingency operations, periods of low aircraft availability, time compliance technical orders (TCTO), other preventive maintenance, and pilot-training requirements would be more limited and only serve to defeat mission accomplishment. In a perfect world, this alternative would be an optimal solution; however, equipment, weather, and human requirements demand more flexibility not inherent in this option.

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Drawing on the operational systems performance data already being collected, engineers could reevaluate the FMECA for each type of aircraft and realign the inspections into intervals based on the new failure projections, establishing preventive tasks as required based on the analysis. The MSG-3 construct facilitates shifting the most time-consuming, major structural inspections to the heavy PE inspections later in the phase or isochronal cycle, which allows the light-to-medium HPO inspections to concentrate on systems reliability.

Option 3 - Hybrid Solution

Whereas the first and second options are merely administrative changes (improvements within an existing construct), the third option changes the model by employing RCM and MSG-3 concepts to their maximum extent. First, the entire inspection continuum requires a top-to-bottom reevaluation using the analysis developed under MSG-3. Drawing on the operational systems performance data already being collected, engineers could reevaluate the FMECA for each type of aircraft and realign the inspections into intervals based on the new failure projections, establishing preventive tasks as required based on the analysis. The MSG-3 construct facilitates shifting the most time-consuming, major structural inspections to the heavy PE inspections later in the phase or isochronal cycle, which allows the light-to-medium HPO inspections to concentrate on systems reliability.[55] These minor inspections can be packaged into 6-hour segments and completed during nonflying periods of the day or week at the aircraft's assigned base. Therefore, aircraft would only need to be flown to the regional inspection facility for PEs requiring more rigorous repairs or refurbishment not possible at the home station.

By employing MSG-3 on their Boeing 737 (B737) fleet of 447 aircraft, Southwest Airlines has been able to sustain over 3,050 flights daily with 435 of their aircraft. This equates to 97.3 percent of their fleet dedicated to the daily flying schedule. Southwest Airlines accomplishes all of their light and medium inspections overnight at airports and their heavy inspections at one of three regional locations. Using the MSG-3 model, Southwest Airlines anticipates each B737's 30-year life span will only require 82 days of downtime for scheduled inspections, resulting in a 99.97 percent aircraft availability rate throughout the aircraft's life span.[56] Annually, this downtime averages 2.73 days, or 0.7 percent, per aircraft.

Analyzing this hybrid option against the aircraft availability criterion would produce the greatest benefits by far. While no US military examples of a total conversion to an MSG-3 approach exist, AFMC has begun an MSG-3 conversion study for the C-5 fleet. The realignment of newly developed inspection tasks lengthened the 105-day, 420-day, and 840-day isochronal inspections to 120, 480, and 1460 days, respectively.[57] The net effect is to increase C-5 fleet aircraft availability by 5 aircraft per year, a 4.5 percent increase in aircraft availability.[58]

Applying the MSG-3 construct to the F-15 inspection continuum would allow the preponderance of structural inspections to be accomplished during PE checks. Consequently, HPOs could be limited to systems inspections and packaged into smaller segments that could be accomplished across several days during nonflying periods. For example, currently an F-15 averages 450 hours per year undergoing scheduled phase inspections.[59] The complete F-15 phase cycle takes approximately 5 years to complete, averaging 94 days of scheduled downtime per aircraft during that period. Because PEs require 10 days out of this entire cycle, the ability to be able to accomplish all HPOs on the ramp would add 84 days of aircraft availability over 5 years, or nearly 17 days per year for each F-15. The total extra

days of availability across the fleet of 482 aircraft would be the equivalent of gaining 17 additional F-15s per year and equates to a 4.6 percent increase in aircraft availability.[60] For FY06, the availability rate of 68.7 would have increased to 73.3 percent, surpassing the Air Force goal of 68.5 percent.[61] While it is unrealistic to assume that the aircraft would remain mission capable during the HPOs, estimating a 25 percent nonmission capable time during the inspections would still yield an additional 17 aircraft per year and a 3.5 percent increase in availability.

The KC-135 fleet would likewise benefit from an MSG-3 analysis and inspection approach. Over a 10-year period, each KC-135 was unavailable for an average of 23 days a year due to scheduled isochronal inspections.[62] The KC-135 is required to complete an entire isochronal cycle of six inspections within 12 months.[63] Assuming that five of the six light and medium HPOs consume 13 days and the sixth heavy PE accounts for 10 days, the MSG-3 reevaluation would repackage inspection tasks into 6-hour segments. This would allow the light and medium HPOs to be conducted at the base, while the heavy PEs would occur at a regional inspection facility. Consequently, each KC-135 could be available 13 additional days per year, increasing the fleet availability rate by 3.5 percent. The total extra days of availability across the fleet of 530 aircraft would be the equivalent of gaining nearly 19 additional KC-135s per year, equating to an increase in availability from 61.4 to 64.9 percent for FY06, surpassing the Air Force goal of 61.4 percent.[64] Assuming a similar 25 percent nonmission capability during the minor inspections would still yield 14 additional aircraft and a 2.9 percent availability rate increase.

Of course, this hybrid option is not without significant costs. Conducting the MSG-3 analysis requires a substantial investment in time, resources, and personnel. However, one aviation maintenance expert predicts "conversion to an MSG-3 based maintenance schedule will provide significant and tangible returns [with] as much as a 30 percent reduction in scheduled maintenance costs."[65] For the C-5 fleet, AFMC has invested approximately $7M to date to standardize historical performance data and conduct a complete FMECA evaluation of all the aircraft's systems.[66] This effort began in 2002 with a staff that included engineers, analysts, systems technicians, maintenance overhaul representatives, OEM representatives, flight crews, and quality assurance personnel.[67] Their strategic intent was to reduce costs and increase aircraft availability by increasing inspection intervals without compromising safety.[68] These goals have yielded a cost avoidance of 32 percent for the C-5As and 5 percent for the C-5B fleet through the interval changes.[69] Although the finalized cost data has not been fully tabulated, the cost avoidances are in the multimillion dollar range due to the inspection interval changes.[70]

Applying a similar percentage based on the C-5's financial gains against the two test case aircraft would most likely yield similar investment costs and cost avoidances due to the MSG-3 efforts. If a modest 10 percent cost avoidance factor were applied to the F-15 unit-level consumable costs, the annual savings could amount to $9.46M per year (10 percent of the average costs during FY97-FY06).[71]

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Unlike under Options 1 and 2, the hybrid alternative maximizes unit control of assigned aircraft. This option enables the unit to conduct its light and medium inspections at the base using the MSG-3 approach. Being able to break inspections into small, 6-hour blocks enables a unit to more readily control the inspection flow to better meet unforecasted requirements, taskings, and AEF deployment demands.

However, an estimated cost to conduct the MSG-3 study for the F-15 fleet could total as much as $10M. Amortizing the $10M cost of the MSG-3 study across the entire fleet of 482 aircraft would amount to a onetime investment of $20,750 per aircraft. The net savings across the FYDP of 5 years would include the $10M MSG-3 study cost and the $47.3M cost avoidance in unit-level consumables, yielding a net FYDP savings of $37.3M.

If the same modest 10 percent cost avoidance factor were applied to the KC-135 unit-level consumable costs, the annual savings could reach $8.28M (10 percent of the average costs during FY97–FY06).[72] As with the F-15, accounting for the $10M investment to conduct the MSG-3 study across the fleet of 530 KC-135s would produce a cost per aircraft of $18,870. The net savings across the FYDP would include the $10M MSG-3 study cost and the $41.4M cost avoidance in unit-level consumables, yielding a net FYDP savings of $31.4M.

Moreover, this hybrid option would accrue the $23.4M savings projected from the reduction of 402 personnel due to the PBD 716 manpower cuts. However, rather than moving all remaining 1,555 inspection personnel to regional facilities, only a percentage would be required at the central inspection sites, due to the MSG-3's lengthened intervals for heavy inspections. Therefore, a greater percentage of inspection personnel could remain within their unit to assist with the onsite light and medium inspections. Furthermore, the inspection personnel would be assigned to the sortie generating squadron so that they could form the inspection cadre to accomplish the light and medium checks, train other flight line personnel in these duties, and contribute to sortie generation activities during slack inspection periods. Because of the realignment of inspection tasks and lengthened intervals, fewer aircraft would flow through the regional inspection facilities. Assuming that the heavy PE inspections would account for one-sixth of all current base-level inspections, as is the case with the F-15 and KC-135, then just one-sixth of unit inspection personnel would need to be assigned to the regional facility. Even if 20 percent of the 1,555 inspection personnel were required to perform the heavy PEs, only 311 personnel would need to be relocated to the regional sites—a substantial cost savings compared to Option 2's requirement to move all 1,555.

Finally, unlike under Options 1 and 2, the hybrid alternative maximizes unit control of assigned aircraft. This option enables the unit to conduct its light and medium inspections at the base using the MSG-3 approach. Being able to break inspections into small, 6-hour blocks enables a unit to more readily control the inspection flow to better meet unforecasted requirements, taskings, and AEF deployment demands. Furthermore, the unit still retains the inspection personnel who can deploy with them to the AEF location to ensure that inspections are accomplished during the deployment. These benefits are simply not available under the regionalized concept of Option 2.

Summary and Implementation Considerations

This article has examined three options for allowing the Air Force to perform phase and isochronal inspections with 402 fewer personnel. Option 1 retains the current inspection concept of performing the inspections at the base but with 402 fewer personnel. Unfortunately, with less manpower to complete inspection tasks under the current construct, inspection time would increase, causing aircraft availability to decrease. Option 2 sends all aircraft to a regional inspection facility. As compared to Option 1, this option would improve aircraft availability but would require implementation expenditures and significantly degrade a unit's flexibility to accomplish mission requirements and thereby control the health of its fleet.

Option 3 provides a hybrid solution that significantly improves both aircraft availability and unit control. This option requires approximately $10M per aircraft fleet, or $80M across the Air Force's eight aircraft types, to conduct the failure analysis and to determine the inspection task packaging for the MSG-3 approach. The initial investment is minimal when compared to the gains. When analyzed against the F-15 and KC-135 fleets, the MSG-3 approach offers the equivalent of gaining 31 additional aircraft per year from both fleets. This option packages the minor inspections into 6-hour segments that can be accomplished overnight or between sorties by personnel assigned to the sortie generating unit who can continue the inspection rhythm at home station or deployed to a combat environment. Consequently, the unit to which the aircraft are assigned retains both responsibility and authority for the health of their fleet. Pride of ownership, as General Wilbur Creech demonstrated with the dedicated crew chief program during his tenure as commander of Tactical Air Command, is not inconsequential for maintaining and improving aircraft readiness levels. Additionally, Option 3's plan to fly the aircraft to a regional inspection facility for the heavy, structure-focused inspections leverages the regional experience and industrial-type test and repair equipment not found at the base level.

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Most importantly, by fully supporting the most significant Army restructuring in the last 50 years, Option 3 offers significant benefits for Joint operations. In keeping with their emphasis on expeditionary, brigade-sized organizations, the Army is eliminating 36 heavy field artillery units, 10 air defense units, and 19 armor units to build military police, civil affairs, psychological, and biological detection units.[73] As a result, the Army will fully rely on the Air Force and the other Services to provide their artillery fire support through improved precision attack munitions. Option 3's opportunities for increased aircraft availability and unit control establish the foundation for the Air Force to better shoulder this Joint fire support responsibility and increase its relevance in the Joint arena. Even though the savings for Option 2 are greater in the short term, Option 3 provides hundreds more airframes across the entire fleet every year; a long term increase in aircraft availability that more than justifies the initial additional investment. In today's environment of Joint interdependency and constrained aircraft recapitalization, the low-risk, high-yield

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dividends demand serious consideration of Option 3. Table 3 summarizes the key aircraft availability, cost, and unit control data for the F-15 and KC-135 test cases.

To implement a vigorous MSG-3 reevaluation across the eight or more weapon systems candidates, several actions need to be taken. At the Air Staff level, policy and sufficient funding must be established for conducting the MSG-3 review and analyses. The process needs to be formalized, with standardized guidance for mandatory participants [Headquarters United States Air Force, major commands (MAJCOM), system program offices (SPO), and others] regarding responsibilities, time lines, and funding requirements. A decision and approval process for initiating and conducting subsequent iterative MSG-3 reevaluations needs to be established. The lead MAJCOMs for the candidate aircraft need to partner with the SPOs to standardize the inspections flow for the most efficient sequence, devise user-friendly, industry-standard type work cards to improve technician efficiency, and fund AFSO21 consultants to outline the most efficient way ahead. Additionally, the commands must develop acceptable levels of system degradation and formalize them in a revised minimum essential systems list (MESL) to balance mission

COMPARISON OF THE THREE OPTIONS						
	Option 1 Stay the Course		**Option 2 Regionalize Inspections**		**Option 3 Hybrid MSG-3 Solution**	
	F-15	**KC-135**	**F-15**	**KC-135**	**F-15**	**KC-135**
Aircraft Availability (AA)	Decreases 1,177 days* (Equiv of 4 less F-15s/yr; -0.7% AA)	Decreases 4,240 days* (Equiv of 12 less KC-135s/yr; -2.2% AA)	Increases 3,374 days* (Equiv of 9 more F-15s/yr; +1.9% AA)	Increases 4,770 days* (Equiv of 13 more KC-135s/yr; +2.7% AA)	Increases 6,146 days** (Equiv of 17 more F-15s/yr; +3.5% AA)	Increases 5,167 days** (Equiv of 14 more KC-135s/yr +2.9% AA)
			Additional Investment of:		Additional Savings of:	
Operating Cost	No additional savings above $23.4M FYDP Manpower Savings for all Air Force Fleets		$1.93M in FYDP	$1.33 M in FYDP	$37.3M*** In FYDP; $9.46M/FY Thereafter	$31.4M*** In FYDP; $8.28M/FY Thereafter
Unit Control	Retain in Status Quo Approach		Significantly Decreased in Regionalization Approach		Retained in MSG-3 Approach h	

*** Increases/decreases are calculated across the entire fleet of 482 F-15 and 530 KC-135 aircraft.**
**** Accounts for assumed 25% nonmission capable status during light and medium inspections.**
***** FYDP savings deducts the one-time $10M investment for the MSG-3 study; annual savings; thereafter would be based on 5-year savings of $47.3M (F-15) and $41.4M (KC-135).**

Table 3. Comparison of the Three Inspection Options

requirements against sustainment costs. Along with these changes, the new inspection process must be gradually phased in, allowing pilot units to test and refine the new system before employing it across the fleet. Finally, units need to set up training programs for their inspection personnel and employ AFSO21 consultants to assist in transitioning to the new MSG-3 inspection construct. These recommendations would create the type of responsive and predictive inspection environment that would produce improved aircraft availability and reliability with decreased operating costs.

Conclusion

As the author of the Bible verse in Ecclesiastes observed, there is a time for everything, including change. The budgetary decreases across the next several FYDPs mandate that the Air Force reexamine all of its current processes. Driven by the manpower cuts dictated in PBD 716 and 720, the time for changing aircraft inspections is now. Increasing aircraft availability while decreasing operating costs without sacrificing combat capability requires more than mere administrative changes to the Air Force's current phase and isochronal inspection processes.

Compelling reasons exist to radically change the current inspection process. The Air Force's inventory of aircraft has become more geriatric than ever before, leading to increased downtime due to inspections and age-related maintenance factors. Consequently, operating costs for these mature aircraft fleets have soared 83 percent over the last decade.[74]

Compelling reasons exist to radically change the current inspection process. The Air Force's inventory of aircraft has become more geriatric than ever before, leading to increased downtime due to inspections and age-related maintenance factors. Consequently, operating costs for these mature aircraft fleets have soared 83 percent over the last decade.

Because of the projected budget shortfalls, aircraft recapitalization programs will be severely constrained and will take 20 years or longer to fully replace their predecessors. As a result, older aircraft will be forced to continue in service to cover the combat capability gaps until the replacement aircraft achieve full strength. Additionally, the cost of replacement weapons systems has become so great that Congress has enacted legislation to prevent the Air Force from retiring aircraft, forcing older aircraft to be flown and be maintained for longer periods to maximize their return on investment.

Overlaid on these factors is the fact that the Air Force has been engaged in combat operations since 1991 and will likely continue to be for the foreseeable future. The combination of high operations tempo, an aging total fleet, and continual personnel reductions makes it imperative for the Air Force to apply AFSO21 concepts to the aircraft inspection process. The threat of terrorism and asymmetric warfare has forced the Air Force to be continually ready to deploy and fight. The Army's transformation and increasingly joint nature of military operations make it imperative for the Air Force to achieve and sustain the highest levels of aircraft availability possible. With the PBD-driven manpower reductions, the Air Force cannot continue to carry out the current manpower-intensive inspection requirements and still sustain today's levels of combat capability. The MSG-3 approach offers the Air Force an opportunity to fully exploit AFSO21 efficiencies to produce combat-ready aircraft with increased

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availability, reduced cost, and improved unit control through an iterative and responsive inspection construct. Transforming the aircraft inspection process is one approach to produce the efficiencies required to better defend the United States and her allies in the global war against terrorism.

Notes

1. Ecclesiastes 3:1-8, *The Holy Bible, New King James Version*.
2. Department of Defense, *Program Budget Decision (PBD) 720: Air Force Transformation Flight Plan*, Washington, DC: Office of the Under Secretary of Defense [Comptroller], 28 Dec 2005, 11.
3. Department of Defense, *Program Budget Decision (PBD) 716: Directed Offsets - Air Force*, Washington, DC: Office of the Under Secretary of Defense [Comptroller], 20 Dec 2005, 9.
4. Aircraft initially proposed by Headquarters USAF/A4MY in Fall 2005 as potential candidates for regionalized inspections were the active duty A-10, F-15, F-16, F-22, B-1, B-52, C-130, and KC-135 fleets.
5. Lt Gen Donald Wetekam, DCS/Installations & Logistics, HQ USAF/A4, and Lt Gen Richard Reynolds, Vice Commander, HQ AFMC to directors of logistics at HQs AMC, AFMC, ACC, and AFSOC, letter, 8 Apr 2005. This letter directed the 20 percent aircraft availability by FY11. Later, HQ USAF/A4M and HQ AFMC/A4 included the 10 percent cost reduction effort in the Aug 2006 AAIP.
6. Col John Stankowski, Chief, Weapons System Division, HQ USAF/A4MY, Briefing, subject: eLog21 - AAIP, 1 Dec 2006, slides 3-25. The AAIP was formed in Apr 2005 to improve depot overhaul efficiency and parts processes for 20 aircraft fleets.
7. Department of Defense, *Program Budget Decision 716: Directed Offsets - Air Force*, 2.
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9. Headquarters USAF/A4MY, subject: What are the Effects of Aging?, 2 Feb 2006, slide 1.
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34. The complete cycle for an F-15 phase inspection requires an HPO-1, HPO-2, HPO-1, HPO-2, HPO-1, and PE to produce 1,200 phase hours. The HPO-1 contains 494 steps in 77 separate work cards, totaling 120 man-hours. The HPO-2 includes the HPO-1 inspection items and comprises 673 steps in 114 work cards and nearly 201 man-hours to complete. The PE includes both HPOs, has 705 steps in 125 work cards, and requires 239.4 man-hours to complete.
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60. Additional F-15s per year calculated by multiplying fleet of 482 by 17 extra days and dividing by 365 days per year to yield 22.
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Lieutenant Colonel Steven L. Martinez, USAF

Baffled by DAFL

Introduction

The first essential condition for an army to be able to stand the strain of battle is an adequate stock of weapons, petrol, and ammunition. In fact, the battle is fought and decided by the quartermasters before the shooting begins.

—Field Marshal Erwin Rommel

Most observers of Operation Enduring Freedom (OEF) and Operation Iraqi Freedom (OIF) agree that the conduct of major combat operations was successful. However, when experts analyze the logistical performance of United States Central Command (USCENTCOM) and other components of the US armed forces, many critiques arise.[1] Numerous anecdotes of less-than-satisfactory support given to combat units can be found, from the lack of spare parts experienced by ground forces driving into the heart of Iraq[2] to the inability to more effectively coordinate intratheater distribution.[3] These criticisms clearly indicate there is room for improvement. The fact that some of these same criticisms were made in the aftermath of Operation Desert Storm (ODS) in 1991 suggests that, while we may have learned from our mistakes in the past, we have not effected the necessary changes in our logistics operations to avoid repeating them.

Recent discussions have centered on a perceived inability of the regional combatant commander (COCOM) to effectively carry out directive authority for logistics (DAFL). Critics charge that, among many things, the lack of a *single point of contact* for Joint logistics theater management (JTLM) caused the inadequacies. Many of those who point to this shortfall advocate the creation of a theater logistics component commander to fulfill this role. Others disagree with this assessment and highlight problems with force flow, information capability, and other factors as

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Title 10 of the United States Code (10 USC) and subordinate guidance such as Department of Defense (DoD) Directive 5100.1 state that the Services are required to "…provide logistic support for Service forces, including procurement, distribution, supply, equipment, and maintenance, unless otherwise directed by the Secretary of Defense." Joint Publication (JP) 4-0 explains that Services "…will continue to have responsibility for the logistics and administrative support of Service forces assigned or attached to Joint commands" consistent with legislation, DoD directives, and other guidance during peacetime.

key deficiencies. The key to any effort to learn from mistakes, however, is ensuring that the right problems are identified. If we do not identify the true root causes, we may correctly solve the symptoms of the problem, but further exacerbate the underlying ineffective condition. More importantly, we may witness yet another operation in which logistics fails to live up to the warfighters' expectations.

This article explores this topic first by addressing the various sources of guidance—doctrinal, directive, Joint, and Service—that stipulate how Joint logistics is to be conducted. Then, three main areas of Joint logistics operations are discussed: visibility, distribution, and communications and information technology (IT) capabilities. For these issues, a brief historical analysis of their effectiveness in ODS, OEF, and OIF is provided. Lastly, conclusions for each aspect will be drawn and recommendations offered for improving these shortcomings in the future.

The Problem

If the transportation system will support, or can be developed in time to support, the forces necessary to carry out the operations plan, the rest of the logistics can usually be brought into line within a reasonable time.

—General Carter B. Magruder, USA

The main area of dialogue impacting this research involves the division of responsibility for logistics within the COCOM's area of responsibility (AOR). This discussion begins with a review of the responsibilities each of the Services bears with respect to Joint logistics.

The Services and Title 10

First, each of the Services—Air Force, Army, Marine Corps, and Navy—bear the obligation to support its forces worldwide. Title 10 of the United States Code (10 USC) and subordinate guidance such as Department of Defense (DoD) Directive 5100.1 state that the Services are required to "…provide logistic support for Service forces, including procurement, distribution, supply, equipment, and maintenance, unless otherwise directed by the Secretary of Defense."[4] Joint Publication (JP) 4-0 explains that Services "…will continue to have responsibility for the logistics and administrative support of Service forces assigned or attached to Joint commands"[5] consistent with legislation, DoD directives, and other guidance during peacetime. However, the COCOM can utilize all of the Services' resources assigned to the command "under crisis action, wartime conditions, or where critical situations make diversion of the normal logistics process necessary."[6] Therefore, a natural tension exists as two separate entities are responsible for the logistics support of the forces assigned in the COCOM's AOR. Furthermore, the boundary between *peacetime* and *wartime* is difficult to identify, and shifting responsibilities once it has been identified are problematic.

The Combatant Commander

The next issue for consideration is the COCOM's directive authority for logistics (DAFL). The source of this authority is also Title 10 of the United States Code, which states that the COCOM executes this authority by "giving authoritative direction to subordinate commands and forces necessary to carry out missions assigned to the command, including authoritative direction over all aspects of military operations, Joint training, and logistics."[7] From this legislation, several Joint publications further detail this authority so that it can be performed by the COCOM (see Figure 1).

JP 0-2 states that combatant command "…cannot be delegated or transferred,"[9] and JP 4-07 says that this authority pertains to "…assigned forces in specific Joint operations."[10]

It is interesting to note that DAFL is a doctrinal (not legal) term that at times is used as a distinct authority not already inherent within combatant command. For example, DAFL is defined in JP 1-02 as

> Combatant commander authority to issue directives to subordinate commanders, including peacetime measures, necessary to ensure the effective execution of approved operation plans. Essential measures include the optimized use or reallocation of available resources and prevention or elimination of redundant facilities and overlapping functions among the Service component commands.[11]

The lack of reference to the previously determined *combatant command* authority seems to imply that DAFL is somehow a different power. JP 0-2 clouds the topic further because it is contradictory, stating, "Commanders of combatant commands exercise directive authority for logistics and may delegate directive authority for a common support capability."[12] This implies that DAFL is somehow separate from the combatant command that cannot be delegated. Other Joint publications (namely 4-0 and 4-07) further describe a separate DAFL and its applicability to Joint theater logistics operations, but end up diluting or confusing the COCOM's authority.[13] As with all of the other functions for which the COCOM is responsible, there is a staff directorate that manages the logistics issues on his behalf and under his authority.

It is interesting to note that DAFL is a doctrinal (not legal) term that at times is used as a distinct authority not already inherent within combatant command.

Combatant Command—Command Authority (Unique to Combatant Commander)

- Budget, planning, and programming input
- Assignment of subordinate commanders
- Relations with DoD agencies
- Convene courts-martial
- Directive authority for logistics

Figure 1. Combatant Command[8]

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The combatant commander's directive authority does not discontinue Service responsibility for logistic support even if it is being executed by another Service or agency."[18] What is clear, however, is the desire for effective command and control of theater logistics to successfully support combat operations. In the end, how does the execution of DAFL impact the logistics support of combat forces? An analysis of theater logistics in ODS, OEF, and OIF is appropriate to answer this question.

The Logistics Staff

The COCOM's logistics directorate (J4) is charged with "the formulation of logistic plans and with the coordination and supervision of supply, maintenance, repair, evacuation, transportation, engineering, salvage, procurement, health services, mortuary affairs, security assistance, host-nation support, and related logistic activities."[14] The J4 staff performs the following key functions.

- Monitors current and evolving theater logistic capabilities
- Coordinates logistics support with upcoming operations
- Advises the Commander in Chief (CINC) on the supportability of proposed operations or courses of action
- Acts as the CINC's agent and advocate to nontheater logistic organizations[15]

As with all other staff directorates, the J4 takes the actions necessary to ensure unity of effort and accomplishment of the command's assigned mission.[16] "The degree of authority to act in the name of and for the commander is a matter to be specifically prescribed by the commander."[17]

While the COCOM is ultimately responsible to effectively apply logistics toward his operations, how it is achieved is somewhat muddled. For example, JP 4-07 says that "The combatant commander's directive authority does not discontinue Service responsibility for logistic support even if it is being executed by another Service or agency."[18] What is clear, however, is the desire for effective command and control (C2) of theater logistics to successfully support combat operations. In the end, how does the execution of DAFL impact the logistics support of combat forces? An analysis of theater logistics in ODS, OEF, and OIF is appropriate to answer this question.

Discussion

Before any plans can be made to provide an army, logistics must be provided first. History has changed a lot, but logistics has been the crux of every one of these changes; the nail that was missing which lead to the loss of country lead to a lot of those decisions.

—Major General Hugh Knerr, USAAF

The first aspect of theater logistics to discuss is the organization of the headquarters staff and subordinate units. The J4 staff, which manages the overall logistics operation in the AOR, is typically organized as shown in Figure 2.

Logistics Readiness Center

The logistics readiness center (LRC), when established, normally "manages the combatant commander's directive authority over logistics and provides the

coordination required to resolve logistics issues and problems."[19] The LRC may include the following boards or centers:

- Joint movement center (JMC)
- Joint petroleum office (JPO) or subarea petroleum office
- Joint civil-military engineering board (JCMEB)
- Joint facilities utilization board
- CINC logistic procurement support board
- Theater patient movement requirements center
- Joint blood program office
- Joint mortuary affairs office
- Joint medical surveillance team
- Joint materiel priorities and allocation board
- Joint transportation board[20]

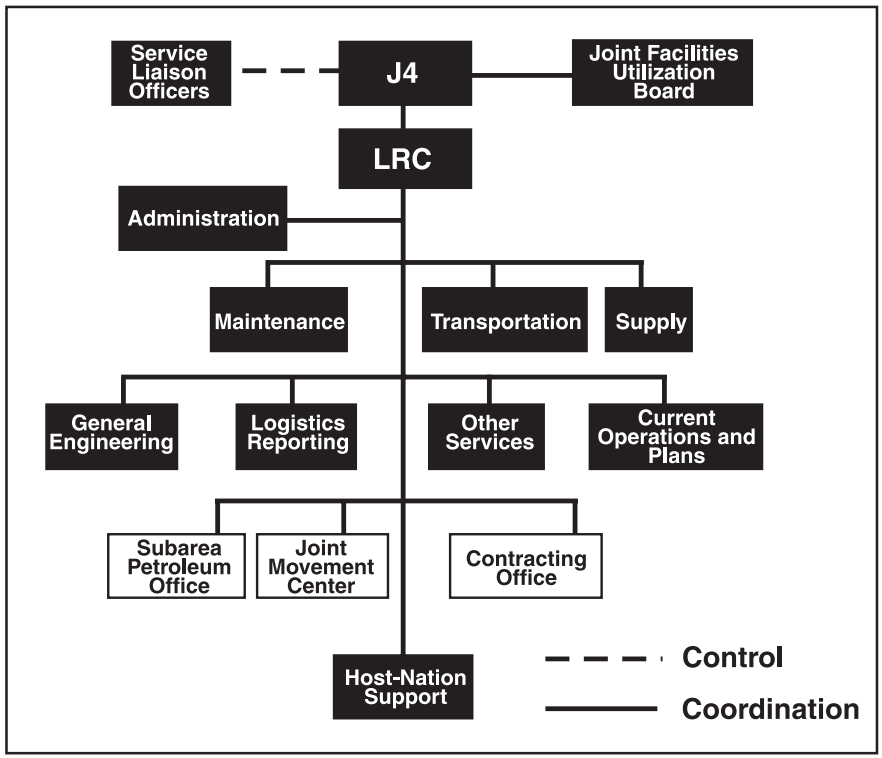

Figure 2. Typical J4 Organization with Logistics Readiness Center

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The COCOM also has the option to utilize these or other organizations to manage logistics when an LRC is not utilized.

Joint Theater Logistics Management

While the COCOM is ultimately responsible for the theater logistics operation, Joint doctrine offers a variety of options with regard to the logistics organizational structure used to attain Joint theater logistics management (JTLM).

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> JTLM integrates the logistic capabilities of the forces intheater to fulfill the common user and cross-Service support mission. When applied to the other challenges and desired operational capabilities of focused logistics, JTLM facilitates support to the warfighter while achieving economies and reducing the logistic footprint. JTLM optimizes resources by synchronizing all logistic support efforts intheater. The objective is to provide rapid, timely delivery of forces, materiel, and sustainment to the combatant commander. JTLM provides to the combatant commander the ability to synchronize, prioritize, direct, integrate, and coordinate common user and cross-Service logistic functions necessary to accomplish the Joint theater mission.[21]

The primary decision the COCOM must make is how to align responsibilities for providing logistics support to subordinate units in the theater. The first choice is to leave the duty of supporting subordinate units with each Service, while the responsibility for common-user logistics (CUL), or the support of items or services used by more than one Service, is limited to preexisting agreements between the Services or coordinated by the COCOM's J4.[22] Some advantages and disadvantages of this construct are as follows.

- Advantages of single-Service logistic support:
  - Does not require new command relationships
  - Allows each Service component to retain control of its own logistic assets
  - Does not require major adjustments to standard operating procedures
- Disadvantages of single-Service logistic support:
  - May require significantly more strategic lift requirements to properly execute
  - May increase operation costs
  - May increase deployment time
  - Will increase logistic footprint in theater
  - May require the use of J4 lead boards and centers to manage specific CUL functions[23]

With the structure shown in Figure 3, the COCOM's J4 would manage the assignment of CUL responsibilities and cross-leveling (reassigning resources from one Service to another), while the determination of logistic priorities for assigned forces remains with each respective Service.[25]

Another option available to the COCOM is to assign a Service or other DoD organization to be the lead agency for CUL support. In this scenario (shown in Figure 4), the COCOM will normally assign the Service that is the most dominant user or the Service most capable of managing the particular commodity or service this responsibility.[26] Also, the use of J4 boards and centers would only be used to "…coordinate or resolve issues above and beyond the capability of the lead Service

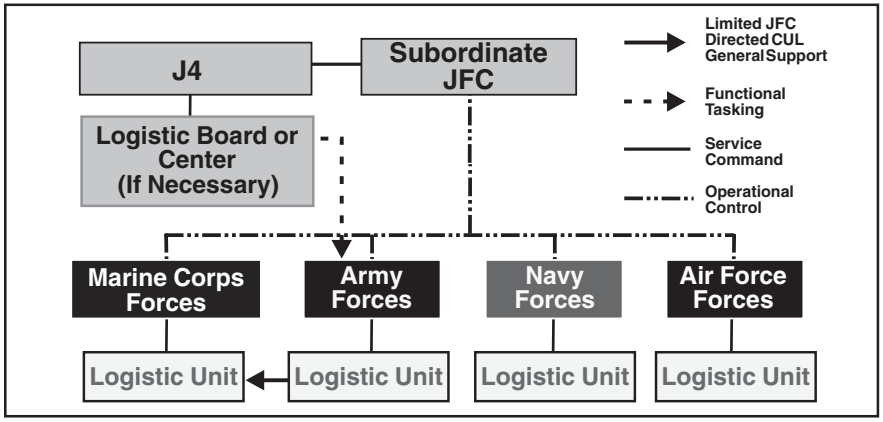

Figure 3. Single-Service Logistic Command and Control and Management Option[24]

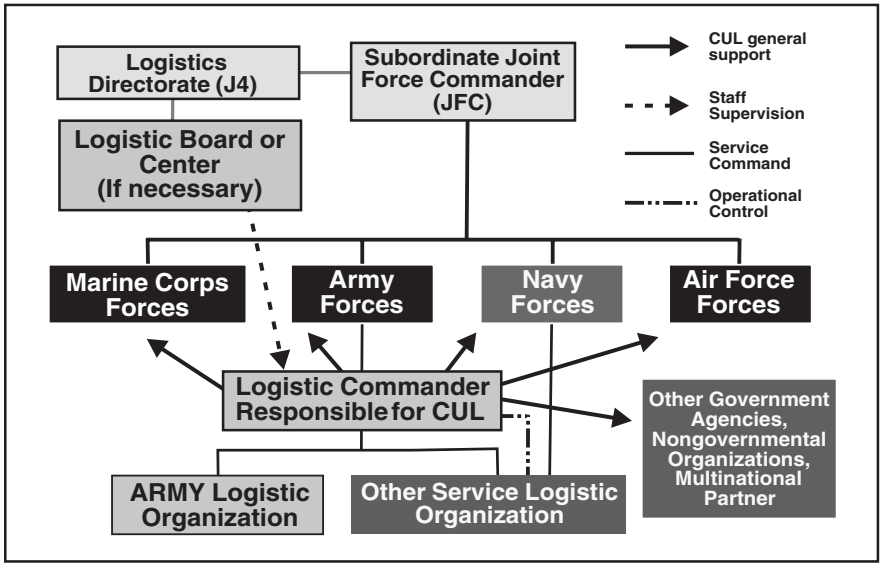

Figure 4. Lead Service Common-User Logistics Command and Control and Management Option[32]

The primary decision the COCOM must make is how to align responsibilities for providing logistics support to subordinate units in the theater.

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In OEF, the deployment and employment of US forces was much more rapid than had been previously seen. The era of expeditionary warfare was upon us, and each of the Services faced a come as you are *situation.*

or agency."[27] Some of the advantages and disadvantages of assigning a lead Service or agency include:

- Advantages of lead Service or agency option:
  - Reduces logistic redundancies
  - May significantly reduce the overall logistic footprint in-theater
  - May reduce strategic lift requirements and deployment time
  - May significantly reduce overall cost
  - Allows each Service component to retain control of its own logistic organizations (without OPCON or TACON option)[28]
  - Requires very little Joint staff, board, or center involvement to properly execute
- Disadvantages of lead Service or agency option:
  - May be less responsive than dedicated Service support
  - Requires new support relationships and adjustments to standard operating procedures
  - Requires new C2 relationships (if OPCON or TACON option is utilized)[29]

Lastly, Joint doctrine also describes situations in which the COCOM may mix features of the two previous options. The spectrum of alternatives for the COCOM's single point of contact for logistical issues includes:

- Using a Service organization as its nucleus; for instance the Army Theater Support Command organizational concept
- Augmenting the J4
- Delegating to a Joint task force (JTF) commander
- Establishing a stand-alone logistic agency
- Expanding the logistics readiness center[30]

JTLM in Previous Operations

The difficulties in establishing the theater logistics organization in ODS are well documented by Lieutenant General (Ret) Gus Pagonis in his book, *Moving Mountains: Lessons in Leadership and Logistics from the Gulf War.* He described a series of improvisational decisions that led to his being chosen as the lead logistician in the AOR.

> Almost as soon as we arrived in Saudi Arabia, Generals Schwarzkopf and Yeosock came to the shared conclusion that the only way they could operate successfully in the theater would be to establish a single point of contact for all logistical needs. I was it—the Deputy Commanding General for Logistics. Responsibility for fuel, water, food, vehicles, ammunition, all classes of supply (except equipment repair parts) for the Marines, Air Force, and the Army, as well as items common to all the Services (T-shirts, socks, and such), was entirely mine.[31]

Then, Pagonis had to pick from among deploying personnel as they entered the theater to become his staff in the Logistics Operations Center (LOC). As more forces arrived, the LOC eventually grew into a more robust organization that included "clusters of transportation experts on one side of the room, fuel people on the other, and nodes of food procurement specialists, airport, and port operations people."[33] Eventually, the 22d Support Command, with Pagonis at the helm, was established to direct the theater logistics operation. In the end, General Schwarzkopf chose to use a lead Service organization, an Army theater support command, to execute theater management of CUL.

In OEF, the deployment and employment of US forces was much more rapid than had been previously seen. The era of expeditionary warfare was upon us, and each of the Services faced a *come as you are* situation. Therefore, the initial logistics C2 rested with each of the Services' forces in the Afghanistan AOR, and COCOM-level issues were handled back at USCENTCOM headquarters at MacDill AFB in Tampa, Florida.[34] A LOC was established under the auspices of the USCENTCOM/J4 to coordinate CUL and obtain materiel and services that the individual Services could not. In addition, a number of Joint boards and centers were utilized in the AOR to orchestrate support for in-country forces. For example, the Joint Movement Center (JMC) took on the responsibility to coordinate the use of transportation resources available in Afghanistan. This function was placed under the direction of the Combined Forces Air Component Commander, located at the Combined Air Operations Center at Prince Sultan Air Base, Saudi Arabia, rather than under the Combined Forces Land Component Commander or a subordinate Army unit. Because the movement and use of organic land transportation assets was not viable, airlift became the main mode used for most cargo or personnel transport requirements at the outset of combat operations. There was a small movement control center that controlled a limited number of military trucks for Coalition Joint Task Force 180 (CJTF-180), the in-country headquarters for OEF.[35]

As more forces, namely Army personnel, flowed into the country, many of the functions managed back in Tampa moved forward and were assigned to the Joint Logistics Command (JLC) of CJTF-180 in Afghanistan. Over time, the JLC assumed more CUL functions and now operates as the single manager for in-country logistics for CJTF-76 (the successor to CJTF-180).

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The operational logistics structure was not much different in OIF. Most of the logistics operation was controlled from USCENTCOM headquarters until late in 2002. At that point, a large number of personnel from the J4 staff moved forward to the AOR. The USCENTCOM/J4 staff operated the various Joint boards and centers, such as the LRC, JPO, and JCMEB. In the meantime, the Services controlled their respective logistics functions and CUL responsibilities. In fact, the Marine Corps created the Marine Logistics Command to control all Marine logistics operations

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The main criticism found in this research was the cumbersome process by which Service components must staff issues for resolution at the COCOM level. If there was a logistics requirement that could not be met by a Service or lead agent, the requesting unit had to coordinate the request through the Service component commander for a decision by the COCOM.

in the Iraqi AOR, mainly the offloading and movement of combat equipment from cargo ships to their units in the field.[36] A clear example of the less-than-optimal arrangement of logistics responsibilities in OIF involves the JMC.

The JMC is "responsible for coordinating the employment of all modes of theater transportation (including that which is provided by allies, coalition partners, or the host nation) to support the theater concept of operations at the operational level with the JTF JMC or component movement center."[37] It is the coordinator for all cargo and passenger movement into, through, and out of the theater and serves as the COCOM's "focal point for strategic movements and should oversee the execution of theater transportation priorities."[38] It is noted that the JMC did not fulfill this role in OIF.

> In USCENTCOM, although there is a Joint Movement Center (JMC), the majority of distribution management is a component activity. At the highest level of the command, that [sic] appears not to have been the intention to execute a fully-functioning JMC. Processes used by the components were component-specific, not integrated into a single theater architecture. There were no common logistics procedures, shared communications, or Joint control.[39]

Furthermore, given its limited capabilities, the JMC focused mainly on intratheater air movements by C-130s with the occasional C-17. Although there was some coverage of intratheater sealift by the Army's theater support vessel, logistics support vessels, and landing craft utility ships, the JMC did not attempt to manage the surface truck movements, delegating this function to the 377th TSC, which further delegated the responsibility to an Army movement control battalion. The lack of Joint visibility and management of common user ground transportation assets limited the Joint access to these platforms, which became primarily an Army-centric transportation fleet. Had the JMC followed doctrinal examples for the establishment of such a body, the common user ground transportation assets may have been more accessible to all of the Services and components.[40]

The last critique of the JMC worth noting here is the disunity of effort experienced in OIF because

> …the Director of Mobility Forces (DIRMOBFOR), the operator of the [airlift] schedule, was not colocated [sic] with the JMC at Camp Arifjan, but was based at Al Udeid AB in Qatar. The DIRMOBFOR would also add cargo to the existing airlift schedule [created by the JMC at Camp Arifjan]. There is little evidence that the JMC attempted to exercise comprehensive directive authority. In a complex AOR, it is essential that a fully functioning JMC be established and operated as a truly Joint command with developed processes and tools. This did not occur in OIF and this dispersion of command across components led to dilution of control.[41]

So while it appears that doctrine describes an integrated and effective JMC, it was not properly established or employed in OIF.

Major Issues in Recent Operations

Both OEF and OIF experienced a combination of logistics organizational options, with the use of Service-focused, lead Service, and COCOM-level units and

capabilities. While there were numerous examples of logistics shortfalls in these operations, those that can be attributed exclusively to doctrinal disparities are few. The main criticism found in this research was the cumbersome process by which Service components must staff issues for resolution at the COCOM level. If there was a logistics requirement that could not be met by a Service or lead agent, the requesting unit had to coordinate the request through the Service component commander for a decision by the COCOM. By the time the issue was reviewed by the appropriate J4 staff office or agency and forwarded for decision, the matter was often overcome by events. In that time, the requesting unit had either moved on to another course of action or fulfilled its need by another means.[42] This was not a universal observation, since the Air Force seemed to be satisfied with the support they received from the COCOM under the organizational structure used in OEF and OIF.[43] However, the pace of combat will only grow faster, so perhaps a C2 structure that can support combat more quickly is needed. In fact, with the increased visibility and information and communications capabilities available through a logistics common operating picture,[44] the COCOM's LRC may actually predict logistics shortfalls and proactively engage to resolve those issues before a Service needs to react.

The second main area of analysis is the conduct of theater distribution, arguably the most important Joint logistics capability during war. The geographic COCOM is responsible for maintaining an effective distribution network and exercising visibility and positive control of personnel, materiel, and services in the AOR. To do this, the J4 manages the overall theater distribution operation by utilizing a series of boards, centers, and committees to prioritize and accomplish the management tasks.[45] The Service components also play a large role in theater distribution, as they provide the units that conduct the day-to-day tasks.

Each of the Services is assigned to perform various segments of the distribution process. These roles, known as executive agent or single manager (SM) tasks, are determined by Title 10, DoD directives, OPLANs, or other instructions. An example of an SM charge is the responsibility of the Department of the Army to provide common-user land transportation (CULT) including rail, in overseas areas, through the Commander, Army Forces (COMARFOR).[46] Therefore, the COMARFOR Director of Logistics (G4) establishes the procedures and determines the requirements to execute this responsibility. Coincidentally, the CULT mission in both ODS and OIF had shortcomings and, thus, has been discussed frequently in literature.

During ODS, the Army Central Command was responsible for providing food, water, bulk fuel, ground munitions, port operations, inland cargo transportation, and construction support for all US forces in the AOR.[47] The CULT function was inadequate for some time, however. Movement requirements outpaced the ground transportation capability throughout the operation, leading some to comment that, had ODS lasted longer, "maneuver forces would have outrun their fuel and other support."[48] One of the main reasons documented for this shortfall was the decision

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by USCENTCOM to flow more combat forces and fewer logistics resources at the start of ODS. "The decision to sequence the deployment of the Service support units later in the deployment flow severely affected the ability of the Army to provide the common-user requirements for the other Services. In some cases, even those logistics forces that did arrive were unable to meet all requirements, and USCENTCOM had to rely on host-nation support to make up the shortages."[49] This situation had a significant ripple effect on theater logistics, especially at the sprawling ports bringing in huge amounts of materiel.

> While the ports were important to the flow of personnel and materiel, the limited initial ability to move troops and equipment away from the ports to their preliminary combat positions became a weak link in the logistics chain. Inadequate numbers of US organic trucks, especially those with good off-road capability, and a limited main supply route network became severe challenges that had to be overcome.[50]

This happened, despite the Army eventually deploying 72 percent of its truck companies to support 25 percent of its combat divisions.[51] This problem was well documented after ODS, so one would think that DoD would take appropriate actions to ensure this did not happen again.

Unfortunately, some of these same problems were also witnessed in OIF. According to the US Government Accountability Office (GAO),

> DoD did not have a sufficient distribution capability in the theater to effectively manage and transport the large amount of supplies and equipment deployed during OIF. For example, the distribution of supplies to forward units was delayed because adequate transportation assets, such as cargo trucks and materiel handling equipment, were not available within the theater of operations.[52]

In addition,

> The 377th Theater Support Command, responsible for logistics support in Kuwait, needed 930 light to medium trucks but had only 515 trucks on hand when combat began, creating a strain on materiel movement. Available transportation assets could not meet the Marine Corps' and the 3d Infantry Division's capacity requirements. High-priority items such as food did not always move as intended. Contractors responsible for moving meals ready-to-eat from ports to the theater distribution center at times had only 50 of the 80 trucks needed. At one time 1.4 million meals ready-to-eat were stored at a port intheater, awaiting transport to customers.[53]

Why did this happen? Once again "DoD did not time the mobilization and deployment of cargo truck units so that the system could be fully prepared to meet anticipated demands from the first day of operations."[54]

> DoD's priority was for combat forces to move into the theater first. A study suggested that distribution assets were either deleted from the deployment plan or shifted back in the deployment timeline. As a result, logistics personnel could not effectively support the increasing numbers of combat troops moving into theater. A shortage of support personnel intheater prior to and during the arrival of combat forces was reported, and those who arrived were often untrained or not skilled in the duties they were asked to perform. The

> shortage resulted in delays in the processing (receipt, sorting, and forwarding) of supplies and backlogs. Contractors performing distribution functions had become overwhelmed and a Joint contractor-military organization quickly evolved. As two divisions entered the theater, the need for a theater distribution center (TDC) became apparent and an area in the desert was designated as a storage and cross-dock area.[55]

This lack of support capability again had enormous negative consequences for the combat forces in-theater.

> The establishment of the TDC only 2 weeks before crossing the line of departure meant that basic processes for support were not functioning, even while in Kuwait. Various units of the 3d ID [Infantry Division] supplied personnel to the TDC to assist operations, but the Division Support Command also routed high priority parts via FedEx to deliberately avoid the TDC. The Air Force stationed a liaison officer at the TDC to divert cargo to Al Jabbar AB, the jumping-off point from their supply convoys. The Marines went straight to the air and seaports to redirect cargo to the Marine Logistics Command at Camp Fox, their version of the TDC. Immediately, all Services began to operate independently.[56]

With respect to theater land distribution, "the failure to effectively apply lessons learned from Desert Shield, Desert Storm, and other military operations may have contributed to the logistics support problems encountered during OIF."[57]

The last area of the logistics operation to be analyzed is the communications and information technology (IT) capability used by logistics forces. DoD has long recognized the importance of improving logistics IT in the 21st century. In fact, a stated goal is to attain information fusion which will provide "a secure, intranet environment allowing DoD users to access shared data and applications, regardless of location, supported by a robust information infrastructure"[58] This will create, "near real-time command and control of the logistics pipeline, one fused picture of combat support to the warfighter, and a closed link between command and control, and combat support during critical execution of an operation."[59] Therefore, any discussion on DAFL and how it is executed must include the information systems that enable C2 of logistics in a COCOM's theater. Unfortunately, this seems to be an area in need of significant improvement.

ODS occurred from 1990 to 1991 at the dawn of the modern computer age. It is understandable that IT was unable to provide capabilities such as total-asset visibility (TAV) that are expected today. These types of shortcomings in ODS are well documented. In fact, the phrase *iron mountain* is synonymous with DoD logistics in the first Gulf War. "During Operations Desert Shield and Desert Storm, asset visibility in the US wholesale system generally was adequate. However, visibility of assets while intransit and intheater was poor. This lack of visibility resulted in considerable confusion and reordering (sometimes multiple reordering) of the same items by field units concerned about existing or projected shortages of crucial items."[60] In essence, the forces lost their trust in the logistics system. These *iron mountains* also came about because the ports, both sea and air, could not definitively know what assets were arriving from the US, so they were ill-equipped to handle the

This lack of visibility resulted in considerable confusion and reordering (sometimes multiple reordering) of the same items by field units concerned about existing or projected shortages of crucial items."

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sheer volume of materials flowing in. The items were then delayed while waiting to be processed, further exacerbating the problem. This problem was not limited to US forces, as the British Royal Army also noted that "one of our greatest failings in the Gulf was our inability to *track assets* and this is even more critical for the support of future operations."[61]

There were also difficulties with the communications capabilities of tactical units that made their sustainment even more tenuous.

> The distance of the supply routes created communications problems within the logistical system because Army officials had difficulty communicating using their equipment, which was designed for much shorter ranges. Military doctrine called for units to be equipped for operating up to 90 miles from main supply bases. However, the Army supported military and logistics bases over 600 miles from its main supply bases.[62]

Therefore, it was difficult for units in the field to input their requisitions for more supplies or equipment and to find out when they would arrive. This also motivated units to overstate their requirements when they actually could input their requests.

This type of behavior results in other subsequent negative consequences for the entire AOR. It further taxes an already limited lift capability that now has to move assets that are not actually needed. In addition, it makes C2 at the COCOM level that much more difficult because it forces the J4 staff and its subordinate boards and centers to play *catch up* and resolve the increased number of bottlenecks that occur. Staff personnel, or the personnel at the ports, may choose to allocate lift resources to move unnecessary assets ahead of others, then not have the lift required to move more important items.

> Unlike combat operators who were deluged with information, logisticians thirsted for it. Without timely and accurate requisition status, up-to-date unit location information, or sufficient ship, aircraft, and container manifest visibility, logisticians could not optimally support battlefield operations.[63]

The 10-year period between ODS and OIF saw a revolution in IT and communications capabilities, but many of the same criticisms were voiced in analyses of the second Iraqi war.

The situation found in Iraq was best described by the GAO when it said, "during Operation Iraqi Freedom, commanders at the senior levels were not able to prioritize their needs and make decisions in the early stages of the distribution process because they did not know what was being shipped to them. The result was an overburdened and overtasked transportation and distribution system."[64] The picture was not much better for distribution within the theater either.

> The lack of intransit visibility over supplies impeded distribution. Because of incomplete radio frequency identification tags on incoming shipments, logistics personnel had to spend time opening and sorting the shipments, significantly increasing processing time. According to US Central Command, about 1,500 small arms protective inserts plates for body armor were lost and 17 containers of meals ready-to-eat were left at a supply base in Iraq for over a week because no one at the base knew they were there. Marine Corps

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> officials became frustrated with their inability to *see* supplies moving towards them and lost trust and confidence in the logistics system and processes. Logistics systems used to order, track, and account for supplies were not well integrated and could not provide the essential information to effectively manage theater distribution.[65]

By and large, "the inability to … reliably, rapidly, and consistently communicate and satisfy logistics requirements limited the effectiveness of established processes during OIF."[66]

So how does this all relate to the analysis of DAFL execution in OEF and OIF? There has been much debate recently over the root causes of the logistical inefficiencies in these operations. Comments such as, "the limited evidence of the exercise of clear directive authority for logistics during OIF is consistent with and a logical consequence of the limitations found in the logistics chain"[67] and "in the case of OIF (DAFL) was not effectively employed"[68] provide the impetus for this discussion. In the course of examining this topic, some organizations recommended the creation of a single logistics commander in a COCOM's theater to alleviate the difficulties. The real problem lies in separating the symptoms of the problem from the actual deficiency-hampering theater logistics.

Key Enabling Capabilities

There are three capabilities that enable effective theater distribution and represent the essence of the COCOM's directive authority.

- Visibility. The ability to monitor the pipeline and obtain positive indicators that the distribution pipeline is responsive to customer needs.
- Theater Infrastructure. A system's infrastructure dictates the capacity of a distribution system and distribution pipeline flow.
- Command, Control, and Communication. The application of control is required to implement the authority of the distribution manager as the focal point of logistic distribution-related functions.[69]

The real problem lies in separating the symptoms of the problem from the actual deficiency-hampering theater logistics.

Analyses of DoD's performance in recent operations (ODS, OEF, and OIF) indicate that these capabilities were deficient. In OIF,

> Lacking tools, process, and structure, the operational control over logistics devolved to the supporting units. Though doctrine empowers the COCOM to exercise directive authority, existing logistics capabilities limit the COCOM's ability to exercise this power. Instead of residing with the COCOM, directive authority for logistics becomes dispersed. This lack of comprehensive focus and control meant that units and battalions were improvising and building ad hoc support systems to ensure their own wellness.[70]

OIF was not without its triumphs as innovative thinking and cooperation led to the creation of the USCENTCOM Deployment and Distribution Operation Center (CDDOC). A C2 cell assigned to the USCENTCOM/J4 and comprised of personnel from USCENTCOM, United States Transportation Command (USTRANSCOM), and the Defense Logistics Agency (DLA), the CDDOC was designed to "link strategic

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deployment and distribution processes to operational and tactical functions in support of the warfighter, thereby improving end-to-end distribution within USCENTCOM's area of responsibility."[71] In order to accomplish this mission, this group was given the following tasks.

- Confirm USCENTCOM deployment and distribution priorities
- Validate and direct Combined Force Air Component Commander intratheater airlift support to components and combined Joint task forces
- Monitor and direct the Coalition Forces Land Component Commander intratheater surface distribution support to components and combined Joint task forces
- Adjudicate identified USCENTCOM distribution and intratheater shortfalls
- Coordinate for additional USTRANSCOM support and materiel
- Set the conditions for effective theater retrograde[72]

It is clear that the Joint deployment and distribution operations center (based on the CDDOC) being implemented by each of the unified COCOMs is a step in the right direction, fusing the right capabilities into a "single point of contact for consolidation and dissemination of deployment and distribution information" that "optimizes information flow between multiple organizations, including coalition, agencies, nongovernmental organizations and other private entities."

The CDDOC, termed by some to be a *JMC on steroids*,[73] offered "enhanced ITV [intransit visibility], reach back and decisionmaking authority, logistics experts within the reach of the warfighter, and actions in force flow and sustainment, all of which assisted the theater operational commanders in the accomplishment of their missions."[74] It is clear that the Joint deployment and distribution operations center (based on the CDDOC) being implemented by each of the unified COCOMs is a step in the right direction, fusing the right capabilities into a "single point of contact for consolidation and dissemination of deployment and distribution information" that "optimizes information flow between multiple organizations, including coalition, agencies, nongovernmental organizations and other private entities."[75] Thus, it addresses and helps to resolve the key constraining factor: the lack of communications and IT to enable visibility of the entire range of theater logistics.

Perhaps the next evolution of this concept is to make it a permanent fixture within the J4 staff of each COCOM so the transition of the unit to contingency operations is not delayed waiting for augmenting personnel to arrive. Another possibility would be to embed the JDDOC function in the new Standing Joint Task Force Headquarters (SJTFHQ) concept. US Joint Forces Command developed the SJTFHQ to provide "each COCOM with an informed and in-place command and control capability, intended to mitigate the challenges encountered as a result of the *ad hoc* nature of Joint task force headquarters formed in the past."[76] Because the SJTFHQ is assembled and maintained prior to force employment, it provides the COCOM with a significant improvement to command and control.[77]

> A dedicated logistics organization responsive to the needs and direction of the JFC should be manned full time by highly trained and professional logisticians who actively participate from the beginning in all Joint operational planning evolutions involving the theater. This organization should be given the opportunity to build internal synergy and external relationships by working closely with the other staff elements and the JFC in deliberate

planning and supporting Joint exercises prior to the beginning of a conflict. Finally, this organization must be given the clear responsibility for performing all theater logistics command and control actions in support of a particular operation.[78]

A Joint Theater Logistics Command?

The advocates for a Joint force support component commander (JFSCC) or similar Joint theater logistics command point to the need for such a "single point of contact" to direct the logistics processes with comments like, "responsibilities for common support lack synchronization and are often in competition with one another and with multinational and interdepartmental agencies," and "no single entity has been given the responsibility for providing the overall command and control."[79] However, doctrine states that there are, in fact, designated points of contact that coordinate virtually every aspect of CUL through the J4's LRC and various boards and centers. In fact, Joint doctrine states that "the LRC is the nucleus of all Joint logistic operations and the nerve center for the supported combatant commander in providing staff direction over Service component logistic systems and requirements."[80] It appears that the JDDOC, as the successor for the JMC function, can finally fulfill the role needed by the COCOM.

Because of the Services' Title 10 responsibilities, CUL is the only facet of theater logistics that the COCOM is expected to plan to control. As situations arise, the COCOM retains the ability to direct actions to ensure the success of the logistics operation. Therefore, the problems do not seem to arise because the proper organizational structure does not exist. Theater logistics is most affected by the factors described previously, namely a lack of visibility, inadequate distribution infrastructure, and communications limitations.

Lack of logistics communication is cited as one of the most pervasive weaknesses in OIF. In an austere theater, the necessary logistics communications infrastructure was not available, and the COCOM did not have the capability to deploy one in support of a rapidly moving combat force.[81]

Other contributing causes, including pushing more combat forces earlier in the deployment and delaying combat support resources, continue to exacerbate the problem and hamper efforts to control theater logistics. Therefore, DoD is unlikely to find more effective outcomes by applying a different organizational construct without resolving these problems.

A major reorganization of logistics command and control, when the evidence suggests that logistics command and control is not a problem, will not necessarily produce more efficient organizations. Increased efficiency should be obtained by reengineering and streamlining current processes.[82]

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Conclusions

Victory smiles upon those who anticipate the changes in the character of war, not upon those who wait to adapt themselves after the changes occur.

—Guilio Douhet

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While the available literature does not negate the JFSCC concept as a viable option available to a COCOM, adding another layer of bureaucracy to the Joint theater logistics organization is unlikely to produce improvements unless these other problems are resolved first. In fact, the JFSCC concept may result in "a loss of flexibility and control by Service components, increased Service manpower costs if [it] fails to eliminate duplication of effort, and a perceived layering of logistics authority."

Accounts of the logistics efforts in OEF and OIF show that, while combat forces were adequately supported, there remains much room for improvement. Most of the literature points out that although the theater commander always had the authority to control logistics, he never had the capability to perform that function—ad-hoc command and control and improvisation were the norm.[83] Among the many shortcomings that made supporting the fight more difficult were "insufficient planning, lack of transportation resources, challenging logistics lines, limited logistics communications capability, and disjointed processes," and "in the end, warfighters simply lost faith in the logistician's ability to get them what they needed when they needed it on the battlefield."[84]

The History Lesson

This situation, which seems to occur in every military operation undertaken by US armed forces, occurs for many reasons, including a lack of visibility of the entire logistics chain, an inadequate distribution infrastructure, and an unreliable communications capability. While the available literature does not negate the JFSCC concept as a viable option available to a COCOM, adding another layer of bureaucracy to the Joint theater logistics organization is unlikely to produce improvements unless these other problems are resolved first. In fact, the JFSCC concept may result in "a loss of flexibility and control by Service components, increased Service manpower costs if [it] fails to eliminate duplication of effort, and a perceived layering of logistics authority."[85]

> In OIF, essential theater logistics processes, organization, and technology were ad hoc creations in response to the exigencies of the conflict. Organizational resources for logistics at the Joint command level were limited; theater logistics command, control, communication, and computer systems were disjointed and often ineffectual; and logistics execution devolved to the component commands. While the COCOM retains the responsibility for theater logistics, he has not been provided with necessary capabilities.[86]

However, visibility is a tool to achieve specific outcomes in support of the following objectives.

- Reliably deliver the required item to the right location in the correct quantity at the time required from the most appropriate source
- Make available tools and information for decisionmakers to exercise effects-based management of the logistics network
- Manage end-to-end capacities and available assets across the end-to-end chain to best support warfighter requirements
- Promote the ability of the supported COCOM to effectively exercise directive authority over logistics[87]

Recommendations

Because of these assessments, and others, DoD should:

- Focus efforts and resources on improving communications and IT capabilities to finally allow the COCOMs and their logistics staffs the visibility needed to effectively control Joint theater logistics operations
- Investigate the efficacy of further enhancing the JDDOC concept by placing it within the SJTFHQ
- Analyze the effects of these root problems prior to directing or further codifying symptomatic corrections such as the JFSCC construct

Until these foundational issues are resolved and solutions fully tested and vetted, DoD will continue to treat the symptoms of our Joint logistics ills. If it does so, the same logistical failures and missed opportunities to properly support our combat forces which have plagued Joint operations throughout our recent history will be observed again in the next conflict.

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Section Three

Studies and Analyses

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Air Force ISO Management: Logistics Enterprise for Containers

Introduction

Since inception, the Air Force munitions Afloat Prepositioned Fleet (APF) has been, and will remain a key pillar of the Department of Defense (DoD) Global Force Management and prepositioning. The Global Force Management construct supplements prepositioned theater munitions with war reserve materiel (WRM) swing stocks to meet a variety of missions throughout multiple theaters. Prepositioning provides the bridge between the early warfighting requirements in a particular theater and the strategic mobility assets required to move these requirements. The primary purpose of Air Force munitions prepositioning is to provide responsive and effective agile combat support (ACS) by positioning munitions where the combatant commander (CCDR) needs them to accomplish the mission.[1]

The Air Force Munitions APF has undergone drastic changes over the last few years; specifically, going from a four-ship construct to a two-ship construct. Another change was allowing each CCDR to utilize both vessels for planning purposes. The transformation that APF has undergone was not only driven by fiscal realities but, more importantly, enhanced ACS will be provided to the CCDRs by enabling an end-to-end enterprise distribution system utilizing the inherent movement capacity of the APF.[2] This transformation caused an excess in International Organization for Standardization (ISO) containers throughout the major commands (MAJCOM) and the APF.

Headquarters Air Force/A4MW, Munitions and Missile Maintenance Division, requested a study from the Air Force Logistics Management Agency (AFLMA) to recommend an economic strategy comparing the use of the common commercial ISO pool to total ownership of ISO containers to meet Air Force contingency munitions needs. Additionally, the AFLMA was asked to make recommendations

Air Force ISO Management: Logistics Enterprise for Containers

The US Air Force APF carries required munitions assets in a forward-based environment. This gives theater commanders greater deployment flexibility by reducing early munitions airlift requirements and allowing rapid movement from region to region as priorities or circumstances change. This supports the Air Force policy of global engagement, enabling quick response to needs of an engaged theater commander or an air component commander worldwide.

that would effectively reduce APF excess ISO container investment. This article documents the relevant background information, problem, objectives, methodology, research, and findings associated with this effort. It concludes with recommendations to realize the cost savings associated with AFLMA's findings.

Let's begin with some background on what ISO really means. ISO is the world's largest developer and publisher of international standards for a large majority of products and services. ISO is a network of the national standards institutes of 157 countries, with one member per country. A central secretariat in Geneva, Switzerland coordinates the system. It is a nongovernmental organization that forms a bridge between the public and private sectors. On one hand, many of its member institutes are part of the governmental structure of their countries or are mandated by their government. On the other hand, other members have their roots uniquely in the private sector, having been set up by national partnerships with industry associations. Therefore, ISO enables a consensus to be reached on solutions that meet both the requirements of business and the broader needs of society.[3]

These standards are used when selecting containers for transporting munitions over international waters, thereby conforming to worldwide safety standards.

Since APF's inception in 1997, there have been considerable changes to the APF structure. Fiscal realities and Pacific Command concerns prompted accelerated consideration of the two-ship APF construct. AF/A4MW conducted a detailed value analysis of APF costs and benefits and concluded that a two-ship APF fleet in the short-term is best served by Motor Vessel (MV) Fisher and MV Bennett. This analysis was validated by Military Sealift Command planners and AF/A4/7 (Logistics and Installations). The decision was made to take an additional APF vessel off-lease at the end of fiscal year (FY) 2008. The MV Chapman went off-lease in FY07. The MV Pitsenbarger discharged select assets in-theater, picked up retrograde, and sailed to the Military Ocean Terminal Sunny Point (MOTSU) and discharged in mid-September 2008.[4]

The US Air Force APF carries required munitions assets in a forward-based environment. This gives theater commanders greater deployment flexibility by reducing early munitions airlift requirements and allowing rapid movement from region to region as priorities or circumstances change. This supports the Air Force policy of global engagement, enabling quick response to needs of an engaged theater commander or an air component commander worldwide. Rapid response swing stocks are used to help fill the differences between the theater's minimum munitions stockpile requirements and on-hand stocks. The APF program is a component of rapid swing stock. The APF weapons mix provides both bomber and tactical fighter support for a variety of missions. The APF program is part of the Global Asset Positioning program. From lessons learned in the Gulf War, the munitions community began working on ways to enhance port handling and intratheater transportation capabilities. The effort centered on the use of ISO 20-foot side opening containers to transport and store munitions earmarked for

contingencies. To support this effort, the APF began working with Military Sealift Command to replace bulk cargo vessels with vessels capable of handling containerized munitions.[5]

The Air Force munitions logistics enterprise owns 5,428 ISO containers and treats them as WRM assets. These containers are prepositioned at various munitions hubs to load immediately to meet any global contingency tasking. The containers also represent a very large inventory investment that essentially doesn't move except on infrequent occasions (see Figure 1). From a cost and effort perspective, should the Air Force continue to maintain ownership of intermodal ISO containers or use a lease option through the Army Intermodal Distribution Platform Management Office (AIDPMO)? What is the best course of action to deal with excess containers generated from the discharge of two APF vessels?

Objectives

This article will address the following objectives:

- Identify the major sources of costs associated with ISO container ownership and management with leasing options.
- Identify areas to exploit cost savings by reducing inventory.
- Provide recommended changes to achieve cost savings.

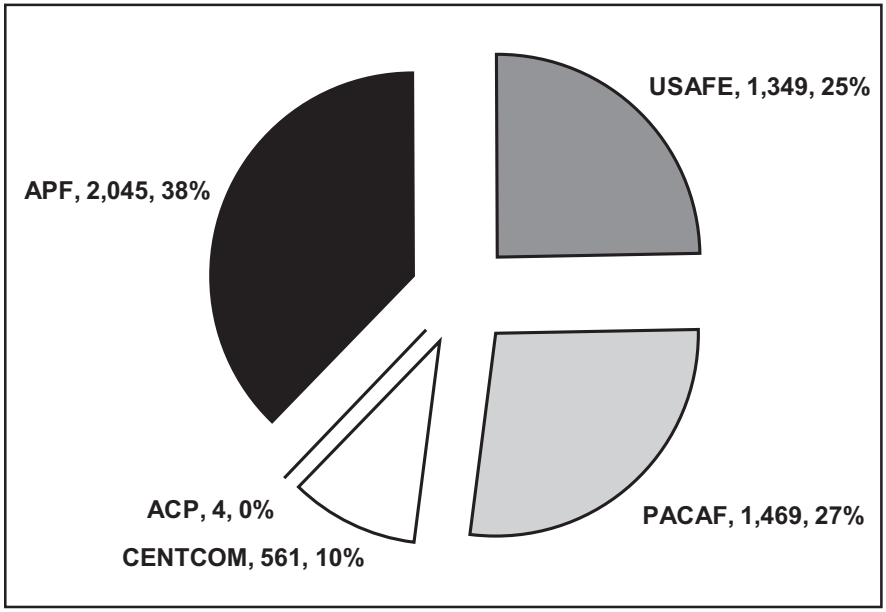

Figure 1. ISO Distribution

The Air Force munitions logistics enterprise owns 5,428 ISO containers and treats them as WRM assets. These containers are prepositioned at various munitions hubs to load immediately to meet any global contingency tasking. The containers also represent a very large inventory investment that essentially doesn't move except on infrequent occasions.

Air Force ISO Management: Logistics Enterprise for Containers

The cost required to manage and maintain all Air Force owned ISO containers, based on 2 years' worth of data from the APF office equates to approximately $9K annually which is $45K over a 5-year period. This cost is primarily attributed to damage the containers may receive during loading and unloading operations. The vessels are climate controlled; therefore no additional weathering damage is incurred.

- To the extent possible, quantify potential savings realized through the adoption of the recommended changes.

Assumptions

This article will assume the following:

- Data collected is accurate and complete.
- Historical data is representative of future operations.

Methodology was based on personal interviews conducted by AFLMA with APF program management personnel, both past and present, via telephone and e-mail. Interviews were also conducted with AIDPMO, Air Force item managers, and equipment specialists associated with ISO containers. Summaries of the interview responses are given in this report. Container data is extracted from the Combat Ammunition System, Agile Munitions Support Tool, and Asset Inventory Management System.

Research and Findings

The discharge of the MV Chapman and the MV Pitsenbarger left an excess of approximately 3,100 Air Force-owned, 20-foot ISO containers throughout four MAJCOMs.

This resulted in excess containers left static at numerous locations throughout the Air Force utilizing precious space, manpower, equipment, and consumables in an attempt to maintain serviceable containers. Required container certifications are not properly managed due to lack of qualified personnel at container locations and lack of funding to secure contractors. This has resulted in 643 unserviceable containers to date.[6] Locations with empty containers do not have certified personnel capable of inspecting or repairing current stocks.

Future requirements for the MV Fisher and MV Bennett require approximately 910 containers.[7]

The lease cost for these containers is based on a maximum lease period of 5 years with an approximate cost of $3.3M for both vessels with container repair as part of the lease. This equates to $3,636 per container over a 5-year period. The initial purchase cost of a single container is $6,684;[8] therefore two 5-year leases would exceed the original purchase price of a container. The cost required to manage and maintain all Air Force owned ISO containers, based on 2 years' worth of data from the APF office equates to approximately $9K annually which is $45K over a 5-year period. This cost is primarily attributed to damage the containers may receive during loading and unloading operations. The vessels are climate controlled; therefore no additional weathering damage is incurred.

Conclusions and Recommendations

Recommendations

Currently, the Air Force has ownership of 5,428, 20-foot ISO containers to support APF, retrograde, and refresh operations. With APF operations now at a two-ship construct, the need for containers has been significantly reduced. Current operations would require 200 at each major depot: Tooele Army Depot, Crane Army Activity, Bluegrass Army Depot, and McAlester Army Ammunitions Plant. The two remaining vessels (MV Fisher and MV Bennett), will carry 1,301 containers, which includes the 391 empty containers currently loaded on the MV Bennett. Thirty containers will be kept at Kadena Air Base to carry out refresh operations and an additional 100 at MOTSU as spares.[9] The total number of containers required to carry out these operations is approximately 2,231, a difference of 3,197 containers from current total ownership (see Table 1).

Annual cost of repair for current balance of 5,428 is approximately $52K annually.[10] Reducing the on-hand number of containers to 2,231 would reduce the annual cost of repair to $22K annually, a savings of $30K. Excess containers, approximately 3,197, could then be transferred to AIDPMO to be utilized by any DoD agency requiring these type containers. AIDPMO will pay for transportation costs to locations that possess the capability to inspect, repair, and maintain serviceable containers. AIDPMO will also accept unserviceable containers and transport them to a repair facility for inspection and repair. Containers deemed not repairable could be turned in to Defense Reutilization and Marketing Service for resale or scrap. See Table 2 for current container quantities, locations, serviceability, and associated value.

The total number of containers required to carry out these operations is approximately 2,231, a difference of 3,197 containers from current total ownership.

AIDPMO has agreed to accept responsibility of all excess containers turned over to their agency to include all transportation costs.[11] The APF and Air Force Materiel Command should coordinate this directly through AIDPMO. The DoD gain of the approximate 3,197 excess containers transferred from APF operations to AIDPMO will reduce the number of containers that the DoD currently leases, while creating significant cost avoidance for the Air Force. Since September 2006 the Air Force has leased 1,874 containers.[12] With the additional 3,197 ISO containers turned in by APF to DoD stockpile (controlled by AIDPMO), leasing containers for munitions movements would be virtually eliminated.

In accordance with Air Force instructions, units will maintain containers in serviceable condition for munitions redistribution or storage at all times. The Convention for Safe Containers certification on all Air Force-owned containers must be kept current. Maintenance, repair, and inspection of ISO containers is a program

Air Force ISO Management: Logistics Enterprise for Containers

element code (PEC) 28030 expense (PEC 55396F for Air Force Reserve Command).[13] The cost to manage and maintain Air Force-owned ISO containers is minor compared to the cost of leasing containers to support these operations. It would be in the best interest of the Air Force to maintain total ownership of sufficient containers to support APF operations and any required retrograde. It is also recommended that the Air Force turn over all excess containers to AIDPMO to manage and maintain. This significantly reduces the storage space, manpower, equipment, and consumables required to maintain serviceable containers. See Table 3 for owning versus leasing cost analysis breakdown.

Location	Container Quantity Required
APF Ships, two	1,301
Tooele	200
Crane	200
McAlester	200
Bluegrass	200
MOTSU	100
Kadena	30
Total	**2,231**

Table 1. Containers Required for APF Mission

Benefits

By reducing the ISO container inventory by 57 percent the repair savings is approximately $150K over the first 5 years. Additionally, transferring excess containers to AIDPMO will allow DoD to utilize over 3,000 ISO containers it would have otherwise had to lease commercially. Furthermore, maintaining ownership of containers required to support the APF mission will help

Location of Container	Quantity of Containers	Purchased Cost	Quantity Serviceable	Purchased Cost	Quantity Unserviceable	Purchased Cost
USAFE	1,349	$9,016,716	1,163	$7,773,492	186	$1,243,224
APF/AFMC	2,045	$13,668,780	2,045	$13,668,780	0	$0
PACAF	1,469	$9,818,796	1,053	$7,038,252	416	$2,780,544
ACP/AFMC	4	$26,736	4	$26,736	0	$0
CENTCOM	561	$3,749,724	520	$3,475,680	41	$274,044
Totals	**5,428**	**$36,280,752**	**4,785**	**$31,982,940**	**643**	**$4,297,812**

Table 2. Breakout of Air Force Owned ISO Assets (data derived from AMST on 25 July 2008)

Ownership Cost Versus Lease Cost					
Owned/Leased	**Number of Years**	**Per Container**	**910[1] Containers**	**2,231[2] Containers**	**5,428[3] Containers**
Air Force Owns Containers Cost[4]	5 year	$48.55	$44,180.50	$108,315.05	$263,529.40
	10 Year	$97.10	$88,361.00	$216,630.10	$527,058.80
Leased Cost[5]	5 Year	$3,636.00	$3,308,760.00	$8,111,916.00	$19,736,208.00
	10 Year	$7,270.00	$6,615,700.00	$16,223,832.00	$39,461,560.00

Table 3. Cost Comparison; Notes: [1]projected requirements for the MV Fisher and Bennett, [2]total number of containers to fully support APF missions, [3]current on-hand balance of containers, [4]Air Force owns containers and only needs to pay for maintenance and upkeep, and [5]leases containers from a commercial ISO pool and includes maintenance and upkeep

provide responsive and effective ACS by allowing the flexibility total ownership provides and cost avoidance of approximately $16M.

Notes

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Analyzing Air Force Flying-Hour Costs

Introduction

We've all, at one time or another, walked into a room and flipped on the light switch, only to hear the *pop* of a light bulb going out. In terms of wear and tear, is leaving a light turned on day and night a quicker route to failure than turning the switch on and off excessively? The light bulb is a good example of certain components that are more likely to fail when being turned on and off than operating continuously. This phenomenon is known as *failure on demand*. When Headquarters Pacific Air Forces (PACAF) asked the Air Force Logistics Management Agency (AFLMA) to evaluate the idea of flying more F-15C/D sorties at reduced average sortie duration (ASD), *failure on demand* was just one of a variety of component failure modes considered. In less than 1 month's time, the AFLMA team illustrated not only the proposed sortie duration change's impact to the cost per flying hour (CPFH), but also how varied modes of failure influence the nature of aircraft breaks.

In the end, the study team would identify five ways in which aircraft and parts fail, as well as the effect varying sortie durations have on each failure mode. The analysis indicated that CPFH will increase as ASD decreases, irrespective of the amount of sorties or hours flown. The research and findings contributed to PACAF's design of the Kadena AB F-15C/D flying-hour program. The results proved to be both rapid and beneficial, including most notably an 18 percent improvement in the mission capable rate after just 2 months time.

Background

When the study team was first approached, Kadena AB was experiencing a higher number of F-15 C/D maintenance issues than other F-15 C/D bases. For some time, mission capable (MC) rates had been approximately 20 percent lower than other F-15 C/D units, and Kadena AB had failed to meet any (all ten) Air Force F-15 C/D

Analyzing Air Force Flying-Hour Costs

Aircraft part costs for each fiscal year are broken down into consumable and repairable parts; however, this research aggregated these categories to simply aircraft parts. Aviation fuel represents the cost of fuel used throughout the fiscal year. Modifications and sustainment costs represent planned depot modifications and weapon system upgrades. CPFH is calculated by adding the three major cost variables and dividing by the number of hours flown throughout the fiscal year.

maintenance standards from May through June 2005.[1] With the intent of reducing an already heavy maintenance burden, Headquarters PACAF was considering the idea of reducing Kadena's F-15 C/D average sortie duration to reduce the overall number of flying hours accrued by each aircraft. However, PACAF maintenance leadership believed that reducing ASD would have a negative effect (increase) on the CPFH for Kadena's F-15 C/D fleet. In the absence of any measurable data that directly addressed this claim, the study team would need to address the following items:

- Define the CPFH model and the data used to compute hourly costs
- Identify Air Force maintenance metrics used to represent component failures
- Evaluate the factors contributing to component failure and reduced aircraft reliability
- Through statistical analysis, establish a lack of correlation between ASD and component failures

While the first three items could be accomplished through a review of existing literature and Air Force regulations, the last would require more extensive analysis. This analysis was necessary since illustrating a lack of correlation between ASD and component failures would validate the following sequence of logic:

- If component failures are not correlated to ASD, then an airframe can be expected to experience the same number of component failures per sortie, regardless of sortie duration.
- If an airframe experiences the same number of component failures per sortie, the same number of repair parts (consumable and repairable) will be required.
- If the same number of repair parts is required, the cost of parts will remain unchanged.

Once these assumptions were validated, changes in CPFH could be calculated, factoring in the following general assumptions:

- Modification costs will remain unchanged across all ASDs.
- The cost of aviation fuel will change linearly with changes in ASD. This assumption suggests that if ASD decreases by 10 percent, fuel consumption will also decrease by 10 percent and the resulting fuel costs will decrease by 10

$$\frac{\text{Parts + Fuel + Modifications}}{\text{Hours Flown}} = \text{CPFH}$$

Equation 1. CPFH Calculation

percent. This assumption accounts for a worst-case scenario as fuel consumption will most likely not be linearly related to ASD because of the fact that excessive fuel burn is encountered during the takeoff phase of flight.

- For the purposes of valid cost comparison, paired scenarios must hold constant either the number of sorties or the number of hours flown. This is to ensure a fair comparison in the spirit of *apples to apples*. For example, it would not be valid to compare a 1.65 ASD, 500-sortie scenario (825 flying hours) with a scenario of 1.5 ASD, 600 sorties (900 flying hours).

Analysis and Research

Kimbrough identified the three major cost variables of the aircraft CPFH calculation model to be:

- Aircraft parts
- Aviation fuel
- Modifications and sustainment costs.[2]

Aircraft part costs for each fiscal year are broken down into consumable and repairable parts; however, this research aggregated these categories to simply *aircraft parts*. Aviation fuel represents the cost of fuel used throughout the fiscal year. Modifications and sustainment costs represent planned depot modifications and weapon system upgrades. CPFH is calculated by adding the three major cost variables and dividing by the number of hours flown throughout the fiscal year. Equation 1 illustrates this calculation.

Manuel discovered that 70 percent of total aircraft flying program costs were attributed to repair parts, 19 percent were attributed to aviation fuel, and 11 percent were attributed to modifications and sustainment.[3] Assuming these ratios can be applied to strategic CPFH models across any weapon system, we are able to estimate CPFH changes based on ASD and the number of sorties flown.

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Ebeling identified five different methods of inducing a failure:

- Hourly operation time
- Operating cycles
- Clock time
- Failures on demand
- Maintenance-induced failures[4]

Component failures attributed to *hourly operation time* should experience fewer failures per sortie as ASD (and the resulting total operating time) is reduced. However, if the number of *low ASD* sorties is increased to achieve the same number of flying hours as the baseline ASD, the number of *hourly operation time* failures will remain unchanged. Components failing based on an *operating cycle* failure distribution, fail based on the number of uses. Therefore, flying the same number of sorties with

Analyzing Air Force Flying-Hour Costs

The number of failures will remain unchanged for components failing on an operating hour distribution; therefore, these failures will not increase total aircraft operating costs for comparable flying hours.

a lower ASD will result in approximately the same number of operating cycle failures. However, increasing the number of sorties will result in increased failures based on operating cycles. Components failing on a clock time failure distribution should experience the same number of failures regardless of ASD or the number of sorties flown.

Failures on demand may occur when a system is turned on. Sometimes referred to as the *light bulb theory*, this failure mode pertains to light bulbs and many other electrical components that have a higher probability of failure when activated as opposed to normal operational loads.[5] In terms of applying this failure logic to aircraft sorties, if the number of sorties remains unchanged, the number of failures on demand—in this case, electrical failures as well as physical failures incurred during the event demands of aircraft takeoffs and landings—should remain unchanged as well. It follows then, that increasing the number of sorties will yield an increased number of failures on demand. Likewise, the number of maintenance-induced failures should increase, because more maintenance is required to repair an increased number of component failures and perform additional through-flight actions. A maintenance-induced failure is defined as a maintainer damaging a component during repair. The number of maintenance-induced failures increases as the amount of either scheduled or unscheduled maintenance increases. With more sorties, maintenance will increase.

Table 1 summarizes the effect of reducing ASD with respect to the number of component failures based on the different methods of inducing failures described above.

It can be seen from Table 1 that reducing ASD only results in a lower number of component failures when the number of sorties flown remains unchanged. Increasing the number of *low ASD sorties* to achieve the baseline flying-hour program will result in an increased number of component failures for three of the five different failure induction methods.

The number of failures will remain unchanged for components failing on an operating hour distribution; therefore, these failures will not increase total aircraft operating costs for comparable flying hours. Next, it is important to identify metrics capable of providing measurable data that would allow for the examination of

Failure Rate Distribution	Lower ASD, Same Sorties (Reduced Flying Hrs)	Lower ASD, More Sorties (Constant Flying Hrs)
Operating Hours	Less	Same
Operating Cycles	Same	Increased
Clock Time	Same	Same
Failures on Demand	Same	Increased
Maintenance Induced	Same	Increased

Table 1. Impact of ASD, Sorties Flown, and Flying Hours on Component Failures

failures based on operating cycles, failures on demand, and maintenance-induced failures.

Of the numerous maintenance metrics tracked by the Air Force, three are of primary interest:

- Break rate
- Pilot-reported discrepancies (PRD)
- Ground abort rate

A secondary maintenance metric of interest is total not mission capable maintenance (TNMCM) time.

The aircraft break rate represents the number of Code 3 breaks divided by the total number of sorties flown.[6] A Code 3 break indicates that an aircraft has a major discrepancy in mission-essential equipment that may require repair or replacement prior to further mission tasking. The break rate is "an indicator of aircraft system reliability ... and is an excellent predictor of parts demand."[7] A sortie is considered to be one operational cycle for an aircraft at the strategic level, and break rates capture the number of grounding breaks per sortie. Break rates convey an expected number of *breaks* per operational cycle, and can supply data for components failing on an operating cycle failure distribution. PRDs can also be used as an indicator of breaks, and account for most Code 2 breaks and delayed discrepancies. A Code 2 break is one in which an aircraft has a minor discrepancy, but the aircraft is capable of further mission assignments.

The break rate is "an indicator of aircraft system reliability … and is an excellent predictor of parts demand."

When an aircrew accepts an aircraft and then encounters a grounding maintenance condition, a ground abort occurs. Basically, this scenario indicates that an aircraft subsystem did not fail until it was placed under an operational load by the aircrew. Preflights and through-flights will test most systems for operability, however many systems will be powered down until crew arrival. Therefore, ground abort rates are the most suitable data source for identifying failures on demand.

Based on the reliability theory depicted in Table 1, the number of component failures should increase as the number of sorties flown increases. The study team hypothesized that the number of failures would increase at an amount proportional to the break rate. For example, a unit flying 100 sorties with a 15 percent break rate can expect to experience 15 failures. Likewise, flying 200 sorties should then result in approximately 30 failures. As the number of sorties increases, PRDs should also increase. TNMCM time should increase as well due to the added repair actions resulting from an increased number of component failures.

A critical piece of this analysis pertained to establishing that ASD has little to no impact on the break rate and number of PRDs reported. If ASD is correlated to break rate and PRDs, we cannot safely assume that aircraft, strategically speaking, fail on a cyclical basis (per sortie), as extended sorties may induce additional wear and tear

Analyzing Air Force Flying-Hour Costs

on components. However, a lack of correlation between ASD and both break rate and PRDs would validate the aforementioned assumption.

Figure 1 shows the correlation matrices for PACAF F-15 C/D maintenance data delineated by command and base. These matrices show no direct relationship between ASD and break rate, nor do they show a direct relationship between ASD and the number of PRDs. Regression analysis confirmed a lack of correlation with an R^2 value of .1851 for ASD to break rate, and an R^2 of .0079 for ASD to PRDs. Therefore, it can be said that changes to ASD are unlikely to bear witness to significant changes in break rate or the number of PRDs. In other words, while the number of breaks will increase as the number of sorties increases, the rate at which the aircraft break remains unchanged.

With the statistical analysis complete, we are able to examine and discuss the specific impact of failures to CPFH under two distinct scenarios. The first is one in which the total number of flying hours is held constant; the second is one in which the total number of sorties is held constant.

ELMENDORF & KADENA COMBINED

	ASD	*Sorties*	*Hours*	*NMCM*	*PRDs*	*Break Rate*	*Fix Rate*	*GA Rate*
ASD	1							
Sorties	-0.423329	1						
Hours	0.459953	0.576527	1					
NMCM	-0.045099	0.100756	0.056012	1				
PRDs	-0.089061	0.432281	0.33525	0.825703	1			
Break Rate	0.430272	-0.51202	-0.131974	0.438816	0.244312	1		
Fix Rate	0.084292	-0.039852	0.059803	-0.876954	-0.726926	-0.394789	1	
GA Rate	0.209038	-0.383863	-0.1771	0.467582	0.293111	0.455907	-0.536551	1

ELMENDORF

	ASD	*Sorties*	*Hours*	*NMCM*	*PRDs*	*Break Rate*	*Fix Rate*	*GA Rate*
ASD	1							
Sorties	-0.437363	1						
Hours	0.383377	0.639519	1					
NMCM	-0.048088	0.184529	0.144108	1				
PRDs	-0.048227	0.457789	0.423036	0.471886	1			
Break Rate	0.545413	-0.507781	-0.107503	0.047028	0.142843	1		
Fix Rate	0.086518	0.016116	0.095437	-0.533626	-0.261427	-0.083821	1	
GA Rate	0.228785	-0.3941	-0.202464	0.267789	0.131635	0.240222	-0.500488	1

KADENA

	ASD	*Sorties*	*Hours*	*NMCM*	*PRDs*	*Break Rate*	*Fix Rate*	*GA Rate*
ASD	1							
Sorties	-0.419614	1						
Hours	0.516478	0.52428	1					
NMCM	-0.118738	-0.089334	-0.150463	1				
PRDs	-0.2127	0.655179	0.436042	0.422141	1			
Break Rate	0.36924	-0.654058	-0.231923	0.543617	-0.079104	1		
Fix Rate	0.202313	0.185897	0.377599	-0.655427	-0.161726	-0.430747	1	
GA Rate	0.230726	-0.581919	-0.291922	0.49828	-0.071508	0.633967	-0.447102	1

KEY

Green Values Approaching 1
Positive Correlation

Red Values Approaching -1
Negative Correlation

Values near zero

No Correlation

Note: correlation does not indicate causality, merely that a linear trend may exist between two variables

Historical data does not indicate strong correlation between ASD and any performance measures

Figure 1. Correlation Matrices for PACAF F-15 C/D Maintenance Data

Flying Hours Held Constant

If ASD is reduced but the number of sorties is increased to maintain a desired flying-hour program, the number of *breaks* (Codes 2 and 3) will increase and the parts required to repair these breaks will also increase. The presumed increase would be linear and proportional to the increased number of breaks. Having established that the break rate remains relatively unaffected by ASD, it is valid to assume it will remain unchanged and produce additional breaks proportional to the increase in sorties flown. For this model, the assumption is that the cost of parts will increase proportionally to sorties flown. Depot modifications and equipment upgrades are planned and scheduled on a fiscal year basis, independent of sorties and flying hours. Therefore, the assumption can be safely made that the cost of modifications will also remain more or less the same over time regardless of ASD or number of sorties flown. Because the number of flying hours remains constant, we will assume the cost for fuel remains unchanged; however, we believe that, realistically, this cost should increase given the greater amount of fuel being expended during the increased number of takeoffs. Referring to equation 1, the increased cost for repair parts will raise the numerator value while all other variables (including the denominator) remain unchanged. With the numerator increasing, and the denominator held constant, we see an increase in CPFH. This model is represented in Figure 2, and although the data used in this research was notional ($6,000 original CPFH for a 1.5 ASD), the same trends are experienced regardless of the cost data used: CPFH increased as ASD was reduced.

Sorties Held Constant

If the same number of sorties is flown over different ASDs, the number of *breaks* (Codes 2 and 3) will remain unchanged and the parts required to repair these *breaks* will also remain unchanged. Furthermore, if the repair parts required remain unaffected by changes in ASD, the cost of parts should remain relatively the same.

Regression analysis confirmed a lack of correlation with an R^2 value of .1851 for ASD to break rate, and an R^2 of .0079 for ASD to PRDs. Therefore, it can be said that changes to ASD are unlikely to bear witness to significant changes in break rate or the number of PRDs. In other words, while the number of breaks will increase as the number of sorties increases, the rate at which the aircraft break remains unchanged.

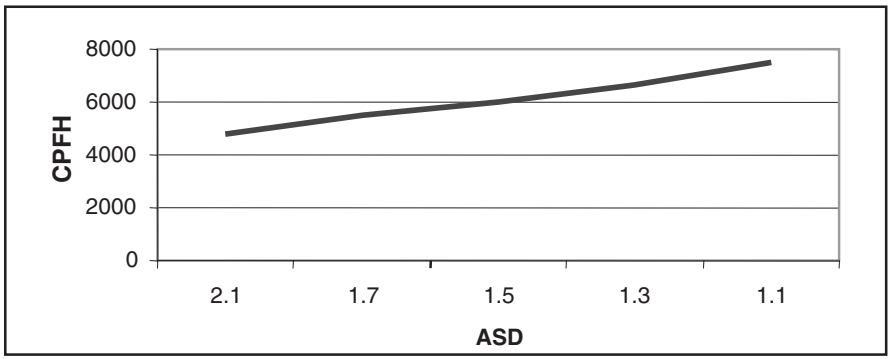

Figure 2. CPFH Estimates: Variable ASD, Variable Number of Sorties, Same Flying Hours

The findings of this research show that CPFH will increase as ASD decreases irrespective of the number of sorties or hours flown. The analysis indicates that reducing ASD cannot decrease the cost of aircraft repair parts, which accounts for approximately 70 percent of the total flying-hour program costs. Reducing ASD and pursuing the same flying-hour program increases the cost of repair parts and significantly contributes to an increased CPFH.

Depot modifications and equipment upgrades are planned and scheduled on a fiscal year basis independent of sorties and flying hours. Therefore, we can safely make the assumption that the cost of modifications will also remain more or less the same over time regardless of ASD or number of sorties flown. As such, when measuring the effect of ASD changes on CPFH, we can hold constant the cost of parts and cost of modifications. With reduced ASDs, it follows that we will observe reductions in quantity of fuel consumed and total hours flown. Under a worst-case scenario, we could assume a perfectly linear relationship between fuel used (and consequently, cost of fuel) and hours flown. For this model, the cost of fuel was assumed to decrease proportionally to the reduction in flying hours (for example, 10 percent fewer flying hours would result in 10 percent lower fuel costs). Realistically, more fuel is likely expended at takeoff versus level flight, but for the purposes of this analysis, we assumed a linear relationship. Since the number of flying hours is simply a manipulation of ASD (that is, the product of ASD and the number of sorties), the same logic can be applied to ASD reduction. Referring to Equation 1 under this scenario, the numerator is decreasing while the denominator is also decreasing. CPFH will increase in this scenario as the numerator is not decreasing at the same rate as the denominator. Therefore, a direct comparison can be made between CPFH calculations for different ASDs. Due to the lack of operational data, notional cost data was used to populate the model represented in Figure 3. The numerical values of the CPFH change; however, the trend established in Figure 2 remains constant—CPFH increased as ASD was reduced.

Conclusions and Recommendations

The findings of this research show that CPFH will increase as ASD decreases irrespective of the number of sorties or hours flown. The analysis indicates that reducing ASD cannot decrease the cost of aircraft repair parts, which accounts for approximately 70 percent of the total flying-hour program costs. Reducing ASD and pursuing the same flying-hour program increases the cost of repair parts and significantly contributes to an increased CPFH. This scenario will require more maintenance effort to generate additional sorties and will require more maintenance effort to repair the additional aircraft breaks.

Notes

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6 *Maintenance Metrics U.S. Air Force,* Gunter Annex, Maxwell AFB, AL: Air Force Logistics Management Agency, 20 Dec 2001.
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Logistics Support: Relating Readiness to Dollars

How to Make Logistics Decisions

Air Force decisionmakers at all levels need tools that relate dollars to operational capability. For example, if the Air Force has $100M, where should it be spent to achieve the most combat capability? A more strategic question is whether to spend the $100M on weapon systems, logistics support, or people.

In the 1980s, the Air Force logistics community realized it needed a way to link dollars to readiness for the resources it managed—spares, equipment, and consumables, as well as munitions and fuel. Since that time, a number of models have been developed to do just that—link dollars to readiness for Air Force-managed peacetime and wartime spares, equipment, and consumables. In this article we briefly discuss the four major models and how they can be used (see Table 1).

In the late 1980s, the Air Force implemented the Aircraft Availability Model (AAM) as part of the Secondary Item Requirements System (D041 then, now D200A) in order to compute the safety-level component for Air Force spares. It has been used since then and continues in use today. The AAM models the complexity of the Air Force spares logistics system. It is a multi-echelon model that maximizes aircraft availability (total nonmission capable supply) given some level of funding. It also models depot- and base-level repair and resupply (retrograde and order and ship times) to a given operations tempo (usually flying hours). Further, AAM includes the spares indenture levels—only

Model	Commodity	Readiness Measure
Aircraft Availability Model (AAM)	Peacetime Reparable Spares	Aircraft Availability
Aircraft Sustainability Model (ASM)	War Time Reparable Spares and Consumables	Aircraft Availability, Sortie Capability, S-ratings, Issue Effectiveness (for Consumables)
Equipment Prioritization	Equipment	Fill Rate, S-Ratings
Customer Oriented Leveling Technique (COLT)	Peacetime Expendable Items (DLA Managed)	Customer Wait Time, Expected Back Orders

Table 1. Tools to Link Readiness to Dollars

Logistics Support: Relating Readiness to Dollars

The AAM uses marginal analysis to build aircraft availability (AA) curves, which can then be used to identify and prioritize what spares to buy with available dollars. Under AAM, the item which creates the largest increase in aircraft availability per dollar (marginal analysis—bang per buck) is the next item selected to buy.

shortages of line replaceable units (LRU) will directly ground a weapon system, while shop replaceable units are needed to ensure LRUs are serviceable.

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Figure 1 illustrates an AA curve and shows that for a given weapon system (or group of weapon systems) the Air Force needs $235M in spares funding to achieve 95 percent aircraft availability. Decreasing the amount of funding by $25M decreases aircraft availability to 94 percent. Figure 2 shows the AA analysis for four weapon systems. This illustrates how Air Force decisionmakers can determine where to take the funding cut and what the impact would be on each weapon system. For example, the Air Force may decide it is better to decrease the B-1 AA by 1.6 percent than to reduce the AA for any of the other weapon systems.

Aircraft Sustainability Model

The Aircraft Sustainability Model (ASM) uses similar logic to the AAM to compute requirements for wartime spares. It computes the minimum cost mix of spares to support a squadron for a 30- or 60-day wartime (War Mobilization Plan [WMP] 5) requirement to a given direct support objective target (which is the number of available aircraft). For example, ASM can be used to compute and assess the spares needed for an F-16 readiness spares package (RSP) to support a 30-day WMP requirement to achieve a 75 percent AA at the end of day 30. ASM is also used to provide a squadron's Status of Resources and Training System S-ratings given a level of spares for an RSP.

ASM has a capability, albeit more limited than the AAM, to link readiness to dollars. ASM is geared for the squadron level—for example, what spares should be bought to increase F-16 availability for a given squadron. Work is ongoing to expand ASM's capability to conduct fleet-wide assessments. An ASM has been built to compute RSPs for expendable items. It provides the least-cost mix of consumable items to meet a given (85 percent) issue effectiveness target.

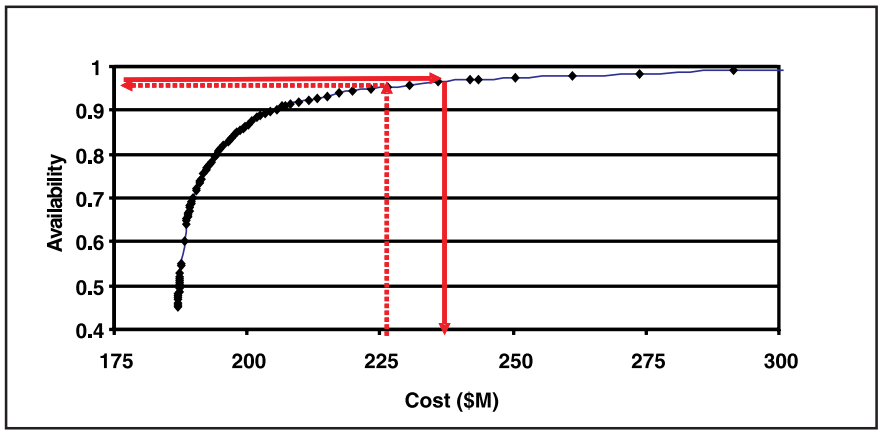

Figure 1. Aircraft Availability Curve

Equipment Prioritization Model

Historically the Air Force has only received 40 to 50 percent of the

funding required for support equipment buys. To make matters worse, there was no way to prioritize what portion of the equipment to buy with the available (less than full) funding. To correct this problem, the Air Force recently implemented the Logistics Management Institute and Air Force Logistics Management Agency-developed Equipment Prioritization Model in the Equipment Requirements System (ERS). This model uses marginal analysis to maximize the number of organizations' equipment fill rates, thereby maximizing the number of fully mission ready (S-rating) by force activity designator (FAD) and use code. Figure 3 illustrates how the Equipment Prioritization Model works.

The model prioritizes to increase the fill rate at the most per dollar. It prioritizes FAD 1, 2 and 3, use code A (mobility) organizations to a higher fill rate target than FAD 4 and 5 organizations. Use code C and D (war readiness materiel) is prioritized next and then use code B (peacetime). The model buys the items up to the fill rate target by *priority bucket* and then, like a waterfall, starts buying assets in the next bucket. Finally, when all of the buckets in a tier meet their fill rate targets, the model starts again at the top for the next tier. In this way, it still buys items for the lower priority units. The model optimizes the number of mission ready mobility and war reserve materiel organizations without neglecting the peacetime requirements. Table 2 shows the prioritization tiers.

The model can be, and is used to:

- Prioritize the equipment buy requirement
- Distribute and redistribute malpositioned equipment

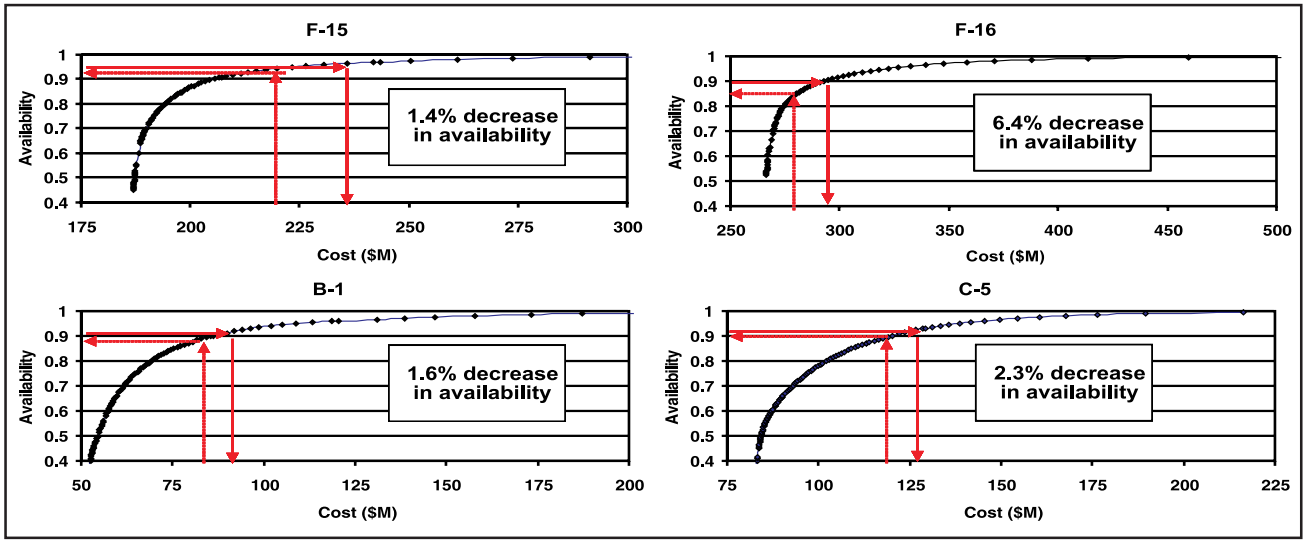

Figure 2. AA Curves - Four Weapon Systems

Logistics Support: Relating Readiness to Dollars

- Prioritize repair
- Allocate operations and maintenance buy dollars

In the past, the Air Force allocated equipment funds to the major commands (MAJCOM) proportional to their gross requirements. If the Air Force received 50 percent funding, the MAJCOM with the greatest authorization total would get the largest share of the funds. For example, if Air Combat Command (ACC) had 70 percent of the gross authorizations, it would receive 70 percent of the available funds. With this is mind, we compared three alternative ways to allocate the available funds—the gross requirement, existing *holes* (net requirement), and the enterprise method (using the Air Force prioritization model).

Figure 4 provides an example comparing the gross requirement baseline to allocating using the net requirement.

In our simple example, Case 1 has 10 authorized and 9 in-use (on-hand) so it needs 1 item. Case 2 has 8 authorized and 4 in-use, so it has 4 holes. The gross authorization method would fund Case 1, since it has the most authorizations, whereas the net requirement would fund Case 2 since it has the most shortages. The gross requirement does not consider the asset position, so fully mission capable organizations could still be allocated funds over units that are not fully mission capable (rated S-2 or lower).

Next we compared the holes versus the enterprise allocation method (see Figure 5).

Case 1 has 1,014 authorized and 108 holes for a fill rate of 89 percent. The organization is a FAD 4, use code B (peacetime) priority. Case 2 has 400 authorized and 92 holes for a 77 percent fill rate for a higher priority requirement (FAD 2, use code A, mobility). The Holes allocation method would allocate to the lower priority need (Case 1). The net requirement does not consider the importance of the shortage to the mission.

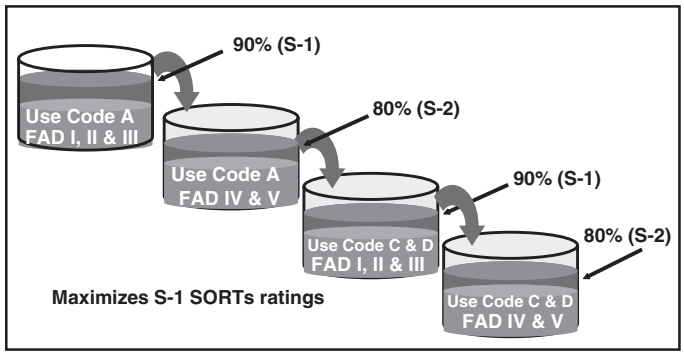

Figure 3. Equipment Prioritization Waterfall

Category	Tier 0	Tier 1	Tier 2	Tier 3	Tier 4	Tier 5	Tier 6	Tier 7	Tier 8
SPRS									
All Use Codes	100%								
Use Code A (Mobility)									
FAD 1, 2, and 3		90%	90%	90%	92%	94%	96%	98%	100%
FAD 4 and 5		80%	90%	90%	92%	94%	96%	98%	100%
Use Code C (Joint Use) and Use Code D (WRM)									
FAD 1, 2, and 3		90%	90%	90%	92%	94%	96%	98%	100%
FAD 4 and 5		80%	90%	90%	92%	94%	96%	98%	100%
Use Code B (Support Equipment)									
FAD 1, 2, and 3		80%	90%	90%	92%	94%	96%	98%	100%
FAD 4 and 5		65%	80%	90%	92%	94%	96%	98%	100%

Table 2. Prioritization Tiers

Figure 6 shows the differences in the allocation based on actual fiscal year 2006 (FY06) funding and asset position. Note the enterprise method allocates more to Air Mobility Command and Pacific Air Forces since they have relatively more net requirement (holes) and more high-priority shortages.

Figure 7 displays the number of S-1 rated (90 percent fill rate or higher) organizations by MAJCOM that could result from a funding allocation (using the Air Force prioritization model to optimally determine what to buy with the allocated funds). The starting position is the number for S-1 organizations with existing (as of FY06) assets before any buy funds are allocated. With the gross requirement, some MAJCOMs cannot get all of their organizations to S-1 (at least to the 90 percent fill rate). The gross requirement does not consider shortages, so funds are not allocated to some MAJCOMs that have relatively low fill rates. With the net holes allocation method, all MAJCOMs expect that Air Force Materiel Command (AFMC) can have all of their organizations achieve an S-1 rating. With the enterprise method, all MAJCOMs can have all of their organizations achieve the S-1 rating.

The Air Force has approved using the enterprise method to allocate available equipment buy funding and is programming that capability into the ERS. Note some equipment buy funds are allocated by program element code (PEC) or some other program (modernization replacement) constraint. ERS will allocate funds to fit the appropriate (PEC or program) constraint. That is, if a certain amount of funds is allocated to a certain PEC, then ERS will optimally allocate to those MAJCOMs within that PEC.

Case 1 Authorized 10, In Use 9 (1 Hole)
Case 2 Authorized 8, In Use 4 (4 Holes)
Gross would fund Case 1 before Case 2
Gross allocation does not consider asset position

Figure 4. Example: Authorized (Gross Requirement) Versus Holes (Net Requirement)

Case 1 Authorized: 1,014; Holes: 106; Fill Rate: 89% FAD IV Use Code B
Case 2 Authorized: 400; Holes: 92; Fill Rate: 77% FAD II Use Code A
Holes would allocate to lower priority need (Org 1) before FAD II Use Code A
Holes method does not consider mission Importance

Figure 5. Holes Versus Enterprise

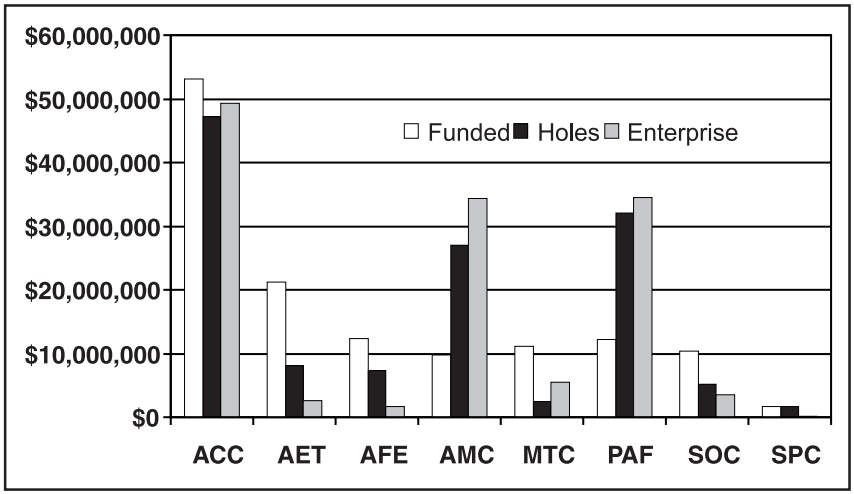

Figure 6. Funding Allocation by MAJCOM

Customer-Oriented Leveling Technique

The Customer-Oriented Leveling Technique (COLT) sets consumable (Defense Logistics Agency [DLA]-managed) levels for the Air Force depot and bases to minimize customer wait time (CWT) constrained by available dollars. It relates General Support Division (GSD) stock fund dollars to base-level (time-

Logistics Support: Relating Readiness to Dollars

The question is what level of DLA SA target will result in the least overall (DLA and base) inventory investment—combined level. The Air Force is working with DLA to explore enterprise models (not just COLT) that address this question.

weighted) expected back orders (EBO) and CWT. In this way managers can relate available dollars to base-level performance. COLT can:

- Link to the DLA wholesale level to reduce the total cost of DLA and base levels to reach a given base CWT target
- Determine how to allocate GSD funds to equalize or target support by MAJCOM, base, or weapon system (for example, provide higher levels of support for contingency bases)
- Identify funding trade-offs for unexpected needs (in the year of funds execution)
- Determine the next item to buy to decrease CWT from an Air Force perspective

Linking Base and DLA Levels

Currently DLA sets (wholesale) levels to achieve an 85 percent supply availability (SA) (off-the-DLA-shelf fill rate) target. COLT then uses that expected (depot delay) DLA performance with the 85 percent SA target to set base levels. For example, if the DLA level for an item is relatively high and therefore there is little expected depot delay (most requests are filled immediately), then COLT would stock less at the base. If DLA increased its SA target, COLT might reduce its base level (see Figure 8).

The question is what level of DLA SA target will result in the least overall (DLA and base) inventory investment—combined level. The Air Force is working with DLA to explore enterprise models (not just COLT) that address this question.[1]

Equalize or Target Support

COLT provides the opportunity to equalize or target support across the enterprise.

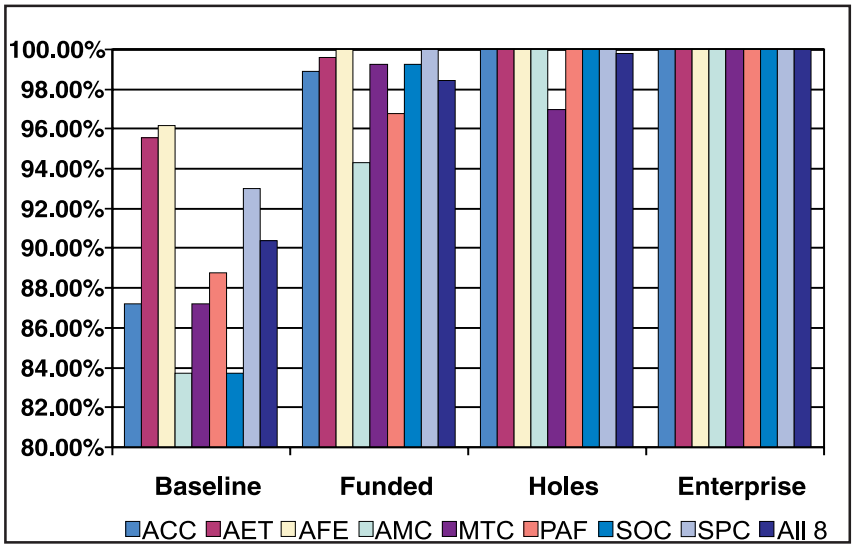

Figure 7. Percentage of SORTS 1 Organizations

The Standard Base Supply System (SBSS) levels (and SBSS levels of funding) do not equalize support. Table 3 provides an example for two C-5 bases, Dover and Travis AFB. COLT is constrained by the amount of funds that SBSS would spend at a base (COLT is run to be cost neutral at a base). Using the SBSS obligations, COLT provides unequal support—an expected CWT (ECWT) of .83 days at Dover and .68 days at Travis.

By changing the funding allocated to each base (without changing the overall obligation funding), COLT can provide equal support—.78 days. However, to do so requires Dover to receive some ($.95M) obligation funds from Travis. The Air Force can use COLT to allocate available funding to provide equal COLT performance (see Figure 9).

Without changing the Air Force obligation total, COLT can better allocate funds to various bases to equalize support.

COLT can also optimize CWT across the enterprise. In fact, the Air Force does so for the air logistics centers (ALC). Figure 10 shows how the Air Force sets COLT levels for the three ALCs. AFMC runs COLT for all three ALCs as if there were a single ALC. COLT then uses overall available ALC funding to set levels to minimize CWT across the ALCs. The result is the lowest overall CWT, but not equal CWT for each ALC.

To illustrate further, refer back to Table 3. The middle row shows the *merged* results for Dover and Travis. Running COLT merging the two bases into *one big base* results in the minimal overall CWT of .75 days. In summary, the Air Force can use COLT as a tool to allocate GSD stock fund dollars to optimize the enterprise CWT, to equalize support across the bases or to target support to various bases. Basically COLT provides the opportunity to take an enterprise view (instead of a base view) for stock fund management and level setting.

Run	Base	Total Obligations	COLT ECWT	DL ECWT
Baseline	Dover	$8.77M	0.82	2.18
Baseline	Travis	$8.66M	0.68	2.33
Merged	Both	$17.43M	0.75	2.25
Match CWT	Dover	$9.73M	0.78	2.18
Match CWT	Travis	$7.70M	0.78	2.33

Table 3. C-5 Example

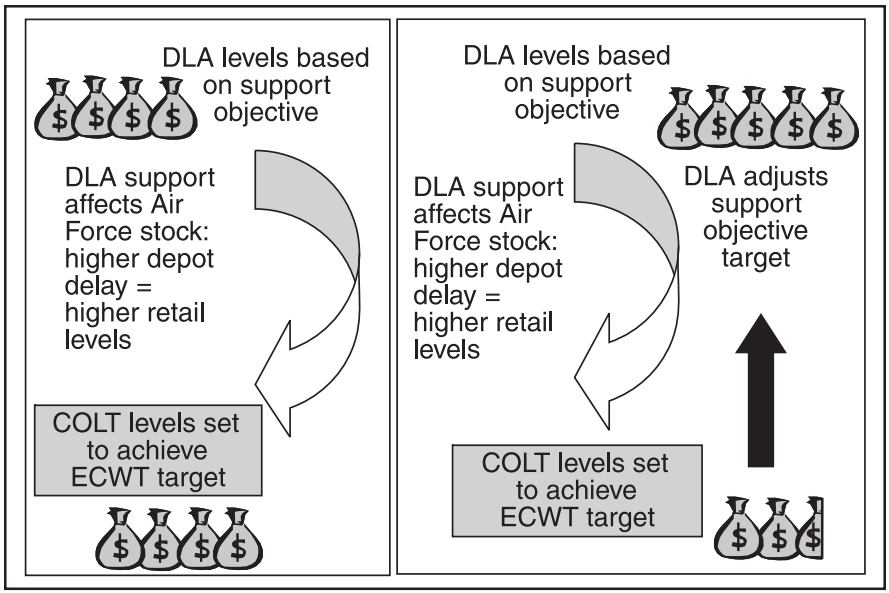

Figure 8. DLA COLT-Linked Levels

Funding Trade-Offs

COLT can provide stock fund managers with the information they need to make funding trade-offs.

Logistics Support: Relating Readiness to Dollars

As Figure 10 shows, COLT can optimally ration the amount of funds left after funds are taken for some other higher priority use. For example, if the Air Force needed some amount of funds for a new stockage policy initiative, COLT can identify the impact on ECWT (and EBOs) of taking money from selected bases, or from each base Air Force-wide.

For example, the Air Force recently set a policy to replace mobile bench stocks with consumable readiness spares packages (CRSP). CRSPs require stock fund dollars to implement and the Air Force wanted to implement CRSPs for the Aerospace Expeditionary Force (AEF) 5/6 rotation. The initial creation of the CRSP required an investment of stock fund dollars. COLT can identify prospective trade-offs for funding. In Table 4 we show three possible options to obtain this funding:

- Taking it all from the home station
- Taking it from the ACC bases using the same mission design series (MDS)
- Taking it from all active duty bases using the same MDS

As expected, when taking all the funds from a single base, the impact (in ECWT) is relatively large on that base. Spreading out the costs to multiple bases (based on the number of mission squadrons) reduces the impact to any one base and overall. Estimates of the four CRSPs needed for the next AEF rotation are $800K.

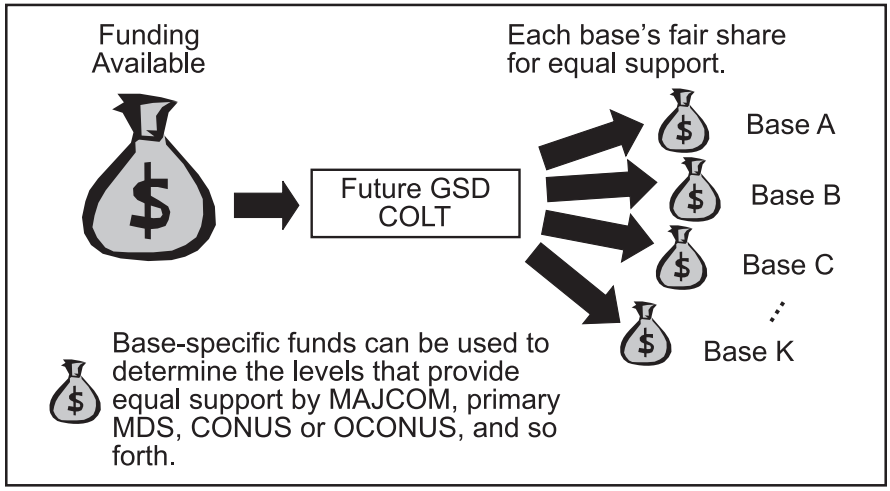

Figure 9. Optimal Merged Levels

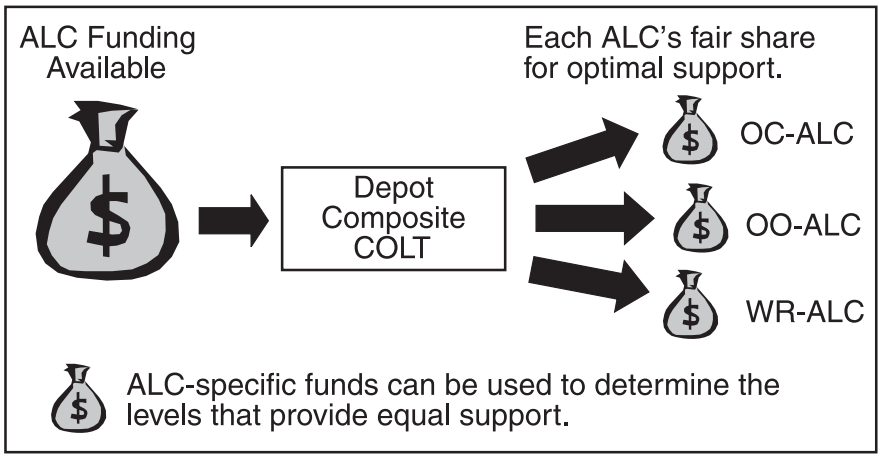

Figure 10. Optimized Levels Current Depot COLT

Buy Prioritization

Just as COLT can be used to allocate funds, it can also be used to execute (determine what items to buy with) those funds. In fact, we've developed a tool—the Funds Requirement Analysis Tool (FRAT)—that optimally

determines the next item to buy if there are insufficient funds to buy the total requirement. FRAT currently is a base-level tool. It prioritizes all the shortages at a base and, given a level of funding, it will create requisition transactions to buy the items that result in the minimum CWT. (Note, this does not change the COLT levels—the requirement—rather it determines what portion of that requirement to buy.)

COLT also provides the opportunity to determine what DLA-managed items to buy next for a group of bases, a MAJCOM, a weapon system, or Air Force-wide. For example, rather than the next item to buy for the F-15 at Langley AFB, what item should the Air Force buy to reduce F-15 CWT Air Force-wide?

Summary

The Air Force now has tools that relate dollars to base-level supply performance and can be used to trade off readiness against dollars. These tools are currently being used to optimally determine what to buy, repair, and distribute with the available dollars. As the Air Force moves to enterprise management organization and systems, these tools, and tools like them, will become more important.

Air Force managers have the information they need to measure the impact of funding cuts on various commodities (spares, equipment, and consumables) to base-level readiness. What is still needed are tools to trade off one commodity for another or one resource (people, fuel, ammunition, spares, and so forth) for another. With the formation of the Global Logistics Support Center, an organization that will need and use the existing models to make enterprise decisions, we anticipate the development of the next generation of models to meet the information needs to manage multiple resources across the enterprise.

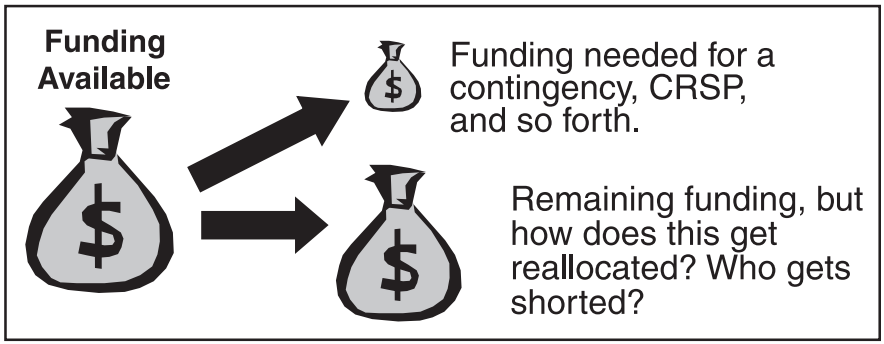

Figure 11. Sourcing Shortages

Option	Bases	Levels Change	ECWT Change
Home Station	Total	22.3K (3.2%)	+0.067 (8.2%)
	Mt Home (100%)	22.3K (3.2%)	+0.067 (8.2%)
ACC	Total	21.3K (1.4%)	+0.025 (3.0%)
	Mt Home (33%)	6.4K (0.9%)	+0.020 (2.4%)
	S-J (67%)	14.9K (1.8%)	+0.029 (3.5%)
Active	Total	18.7K (0.5%)	+0.012 (0.9%)
	Mt Home (17%)	2.8K (0.4%)	+0.009 (1.1%)
	S-J (33%)	7.1K (0.8%)	+0.013 (1.6%)
	Elmendorf (17%)	4.1K (0.3%)	+0.008 (0.4%)
	Lakenheath (33%)	4.8K (0.6%)	+0.019 (1.2%)

Table 4. F-15 CRSP Example

Logistics Support: Relating Readiness to Dollars

Notes

1. An 85 percent SA does not mean every item will have an 85 percent fill rate. Rather, it means that, overall, DLA will satisfy 85 percent of item requests from off-the-shelf stock. Some (relatively inexpensive) items will have fill rates higher than 85 percent and some lower. COLT minimizes CWT, so COLT will stock relatively less of an item with little depot delay.

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DLA Forward Stocking: An Economic Analysis

The Defense Logistics Agency (DLA) supplies Air Force units in the area of responsibility (AOR) with relatively inexpensive, consumable items. The DLA-managed items originate in the continental United States (CONUS), where they are stored and shipped directly to the forward bases in the AOR. DLA recently proposed forward stocking, in which items are stored centrally in theater and then shipped to the AOR bases. Theoretically, forward stocking items should reduce transportation times from the DLA (forward) depot to the forward units. Additionally, forward stocking utilizes less expensive modes of transportation from CONUS to the forward DLA depot.

Previous research has investigated the feasibility of forward stocking relatively expensive, Air Force-managed parts and concluded that forward stocking was not economical.[1] Currently, DLA only forward stocks an item if it has four-or-more demands in a year.[2] The criteria's intent is to ensure only high-use items are stored in theater. This research extends previous efforts by considering the feasibility to forward stock inexpensive, DLA-managed parts according to current DLA criteria, and additional criteria developed through the research. A general methodology is presented to model and evaluate the performance of forward stocking. Although the methodology is applicable to any potential theater, only United States Air Force Central Command (USCENTAF) with storage at Defense Distribution Depot Kuwait (DDKS), is considered in detail.

Research Methodology

A mathematical model was constructed for direct shipping from CONUS to the base, and for shipping to a forward stocking location, and then to the base. Figure 1 depicts the structure of this model.

The model, implemented in Visual Basic, computes the inventory pipeline and transportation costs for each item from CONUS either direct to the air base, or to forward storage and then to the forward base. Inputs to the model are the transportation costs and times of each route, along with the item's cost and daily

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demand rate. It is important to note the characteristics of direct shipping versus forward stocking. Items traveling directly use faster modes of transportation, such as airlift or commercial carriers; therefore, the pipeline time is shorter, and there is less inventory in the pipeline. On the other hand, items forward stored will travel to the forward storage location via less expensive transportation modes (such as cargo ships), and from forward storage to the base via ground convoys or intratheater airlift. These slower but less expensive modes of transportation increase ship time and therefore may require more pipeline inventory. (See Table 1)

	Direct Route	Forward Storage Route
Modes of Transport	More expensive but faster	Less expensive but slower
Pipeline Inventory	Less	More
Safety Level Inventory	Less	More

Table 1. Direct Versus Forward Storage – Inventory Levels and Transportation Modes

Given ample lead time, any item can be economical to forward stock, since the accumulated savings from lower annual costs will eventually break even with and then exceed the one-time investment costs. Forward stocking is considered cost beneficial if the breakeven occurs in less than 5 years (in accordance with Air Force Manual 23-110). Therefore, the model evaluates economic feasibility by computing the breakeven time and the resulting savings or cost over a 5-year period.

Definite data was not available for the shipping costs and times; therefore, they were estimated for each leg of the direct and forward route. The pipeline times from CONUS to the base (days) were extracted from the AOR bases' SBSS routing identifier record. The CONUS to forward storage times estimated were derived from analysis of United States Transportation Command (USTRANSCOM) data. The forward storage to base times were derived from USTRANSCOM-provided pipeline performance based on shipment time from the US Army Material Command. Sensitivity analysis was also conducted with varied pipeline times. Transportation costs were based on AFMAN 23-110, chapter 19. Transportation costs and times are shown in Table 2.

Route	Cost ($/Shipment)	Time (Days)
CONUS Base (Direct)	37	11
CONUS Forward Storage	5	30
Forward Storage Base	20	15

Table 2. Pipeline Costs and Time

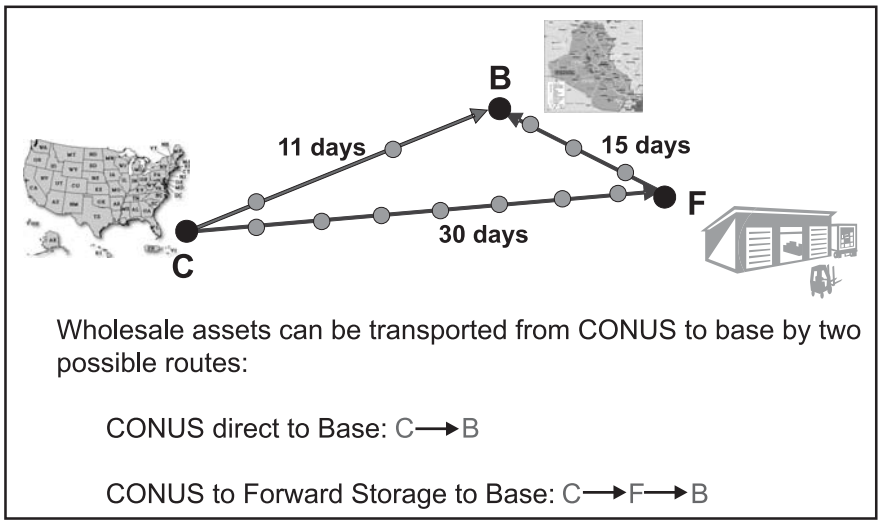

Figure 1. Forward Stocking Model

The model optimally decides if an item is feasible to forward stock and

computes the associated 5-year cost or savings. The optimal model, in turn, enables the development of easier-to-use rules of thumb to select what items to forward stock given a measure to evaluate performance.

Measuring the Performance of a Stockage Criteria

The objective is to develop criteria that identify items that are economical to forward stock. More specifically, the rule should not be one that stocks the highest percentage of items correctly, but one that selects items resulting in the greatest cost benefit. A set of criteria could potentially classify more items correctly than another, but ultimately result in more expense because the mistakes it makes are more expensive. Savings result when an economic item is forward stocked. Savings are the amount of money saved beyond the break-even point over a 5-year period. Likewise, extra expense is incurred when an uneconomical item is forward stocked. The expense is the amount of money by which the savings fall short of the break-even point over a 5-year period.

For a particular item and criteria, there are four possible outcomes (refer to Figure 2). The first outcome is that the item is *economical* and forward stocked. This is a correct decision resulting in savings.

The second outcome is that the item is economical but not forward stocked. This is called alpha-error and the potential savings from forward stocking the item is lost.

Next, an uneconomical item can be forward stocked, resulting in beta-error and extra expense.

Finally, an uneconomical item that is *correctly* not forward stocked has no effect on savings or expense. We seek a rule that minimizes incorrect decisions (alpha

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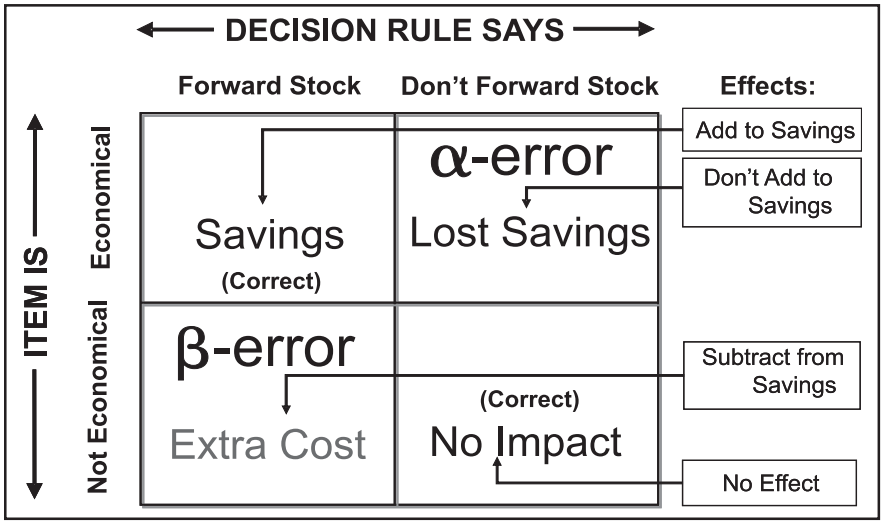

Figure 2. Performance Outcomes

and beta error). However, beta error actually incurs costs (as opposed to a lost opportunity for savings), so it is considered the more egregious error.

Proposed Criteria

Recall that DLA currently uses a demand-only criterion of four-or-more demands in a year. The following modified criteria were developed:

Forward Stock If: Unit Price < Some Threshold -and- Demand ⩾ Some Threshold

Although actual DLA data indicating demand levels were not available, three representative aggregate pipeline inventory levels were constructed for USCENTAF. The first combined demands from five USCENTAF bases: Al Dhafra, Ali Al Salem, Al Udeid, Baghram, and Balad, and represented combined Middle Eastern theater demands. The second consisted of items not currently forward stocked because of insufficient storage space. The third dataset consisted of items currently forward stocked.

The modified criteria ensure that items forward stocked are not only high demand but inexpensive, thereby eliminating excessive pipeline inventory costs. Possession of a model, performance measures, and prospective criteria is not sufficient to conduct an analysis. A list of the items demanded in theater is also required. DLA views theater-wide demand levels; that is, aggregate demand from a number of bases in the theater. Although actual DLA data indicating demand levels were not available, three representative aggregate pipeline inventory levels were constructed for USCENTAF. The first combined demands from five USCENTAF bases: Al Dhafra, Ali Al Salem, Al Udeid, Baghram, and Balad, and represented combined Middle Eastern theater demands. The second consisted of items not currently forward stocked because of insufficient storage space. The third dataset consisted of items currently forward stocked. In summary, the process is as follows for a particular dataset:

- Select cost and demand thresholds
- Compute whether each item is economically feasible to forward stock with cost and demand threshold
- Compare simple rule performance to optimal performance
- Evaluate performance

Results

Analysis was conducted on the combined USCENTAF demands, items currently not forward stocked because of insufficient storage space, and items that are currently forward stocked. Several different sets of criteria are applied to the demand data, and their performance is discussed.

Combined USCENTAF Theater Demands

The combined USCENTAF demands consisted of 24,589 items at Al Dharfa, Ali Al Salem, Al Udeid, Baghram, and Balad as of 30 June 2006. The performance of the current DLA criterion (four-or-more demands in a year) is shown in Table 3.

The current DLA criteria would forward stock 2,483 (1,682+801) items (10 percent of the 24,589). Using this criteria results in a net loss of approximately $675K ($723K - $1.388M) over a 5-year period because of excessive pipeline inventory costs. (Note that the $688K is an opportunity cost and does not actually incur a monetary expenditure. Thus, it does not factor into the net savings

or loss.) This is evident by the 801 items forward stocked that are not economical to stock (beta-error) and the associated cost of -$1.40M that overwhelms the transportation savings of $723K. The total net loss of $675K is over a 5-year period.

Now consider the addition of a cost criterion to DLA's demand criterion (Table 4). The best cost criterion was a cost of less than $50.

Adding a cost criterion prevents an excessive pipeline inventory of expensive items, eliminating virtually all the beta-error. This resulted in a net savings of $679K over a 5-year period. Additional savings is generated by lowering the demand criterion to two-or-more demands in a year (see Table 5).

Lowering the demand significantly lowered the alpha-error, capturing additional savings. The beta-error only slightly increased, and the total net savings was $955K over a 5-year period. This rule would stock 20 percent of the items demanded in the AOR, as compared to the 10 percent of items stocked under current DLA criteria.

Items Not Stocked Because of Insufficient Storage Space

Next, the modified cost and demand criterions are applied to the set of items not forward stocked because of insufficient storage space. A total of 15,819 items met the criteria for a demand level at the using air base, but were unable to be forward stocked at the base because of insufficient storage space. Items that are economical to forward stock should be stored at the Defense Distribution Depot Kuwait (DDKS), Southwest Asia until storage space is available at the forward bases. Items that are not economical should not be stored at DDKS but should remain in CONUS.

Applying the modified cost and demand criterions to the items yields a potential savings of $747K (see Table 6).

A total of 3,026 items (19 percent) met the criteria to forward stock, of which 2,780 are economical. A total net savings of $747K results over a 5-year period. Savings can be increased if pipeline times are reduced. Table 7 shows the performance if the time from DDKS to the forward base is lowered to 5 days.

Although the same amount of items is forward stocked, more items are economical with a shorter pipeline from DDKS. Savings are increased by approximately $85K ($832K - $747K) over a 5-year period. Furthermore, stocking at DDKS is beneficial for all items not stocked at the using base, if the total pipeline time is less than the pipeline time direct from CONUS to the base. Since these

	Forward Stocked	Not Forward Stocked
Economical	1,682 ($723K)	9,920 (-$688K)
Not Economical	801 (-$1.388M)	12,186
Total 5-Year Net Loss: -$675K		

Table 3. DLA Criterion Performance: Demands ⩾ 4/year

	Forward Stocked	Not Forward Stocked
Economical	1,646 ($709K)	9,956 (-$701K)
Not Economical	161 (-$30K)	12,826
Total 5-Year Net Savings: $679K		

Table 4. Performance: Cost < $50; Demands ⩾ 4/year

	Forward Stocked	Not Forward Stocked
Economical	4,510 ($1.026M)	7,092 (-$384K)
Not Economical	507 (-$71K)	12,480
Total 5-Year Net Savings: $955K		

Table 5. Performance: Cost < $50; Demands ⩾ 2/year

	Forward Stocked	Not Forward Stocked
Economical	2,780 ($774K)	5,341 (-$286K)
Not Economical	246 (-$27K)	7,452
Total 5-Year Net Savings: $747K		

Table 6. Performance: Cost < $50; Demands ⩾ 2/year

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items are not stocked at the using base, any pipeline time less than CONUS will reduce back order time. As space becomes available, economical items can be selected for storage at the using base.

Standard Base Supply System (SBSS) demand levels must be adjusted if forward stocked items have different order and ship times (O&ST) than items from CONUS. In the event of reduced forward pipeline times, the reorder point (ROP) can be lowered for forward stocked items yielding a one-time savings. The resulting savings or costs associated with different forward pipeline times were computed assuming all 15,819 items were forward stocked. The results are listed in Table 8.

	Forward Stocked	Not Forward Stocked
Economical	2,861 ($843K)	6,448 (-$337K)
Not Economical	145 (-$11K)	6,345
Total 5-Year Net Savings: $832K		

Table 7. Performance: Cost < $50; Demands ⩾ 2/year (DDKS to Forward Base = 5 Days)

Forward Leg (Days)	Direct Leg (Days)	Cost Difference
1	11	**-$2.6M**
3	11	**-$2.1M**
5	11	**-$1.5M**
7	11	**-$1.1M**
9	11	**-$481K**
11	11	**$0.0K**
13	11	**$357K**
15	11	**$747K**

Table 8. O&ST Cost Differences (Items Not Forward Stocked)

Forward Leg (Days)	Direct Leg (Days)	Cost Difference
1	11	-$21K
3	11	-$16K
5	11	-$12K
7	11	-$8K
9	11	-$4K
11	11	$0K
13	11	$4K
15	11	$7K

Table 9. O&ST Cost Differences (Items Currently Stocked at Forward Bases)

Therefore, if the forward pipeline is reduced to 5 days, there will be a one-time savings of $1.5M in reduced supply levels at using bases, in addition to the $832K saved over a 5-year period under the proposed cost and demand criteria.

Items Currently Stocked at Forward Bases

The final set of items consisted of those currently stocked at forward bases. Currently there are 566 items stocked at the using bases, of which 529 are economical to forward stock. If the ship time from DDKS is reduced to 5 days, 537 items would be economical. SBSS demand levels would also require adjustments to their ROP levels yielding one-time savings. The cost differences for various forward O&STs are listed in Table 9.

If ship time from DDKS is reduced to 5 days, a one-time savings of $12K would be realized.

The Combat Air Force Logistical Support Center identified both the need to reduce the DLA-depot-to-using-base times, and the need to track assets shipped from the forward depot, especially shipments for mission capable requirements. Without adequate tracking, delayed and lost shipments occur which create workload delay, replenishment times, and potentially generate excesses, as other orders are placed to compensate for delayed shipments.

There is a *regional stock* alternative. For example, items can be stocked at DDKS without stocking at using bases. Although this would reduce inventory levels at the using bases, it would increase back orders because of the added ship time from the DDKS to the using base. Therefore, this alternative is not recommended.

Throughout the analysis, it was assumed additional inventory storage costs are not incurred. Applying the

recommended forward stocking criteria still results in savings, albeit at a lower amount. Savings under DLA covered-storage costs is maximized by lowering the cost criterion to $20. Increasing CONUS-to-DDKS ship time to 60 days also results in a lower savings with an optimal cost criterion of $16.

Conclusion

Prepositioning supplies used by forward airbases at a forward storage location in the AOR is a viable alternative to the current practice of shipping items directly from CONUS. An item is economically feasible to forward stock if the annual savings realized by reduced shipping costs exceeds the increased one-time, inventory investment costs within a 5-year period. Performance of both the current DLA demand criterion and the new criteria using cost were evaluated using three different data sets:

- All items with demands in the Middle Eastern theater
- Items not currently forward stocked because of limited storage space, and
- Items currently stocked at using bases

The current DLA criteria results in excessive costs by forward stocking uneconomical items. By adding a unit-price threshold and lowering the demand threshold, about 20 percent of the items used in the AOR are economical to forward stock and would achieve a $747K, 5-year savings. A sensitivity analysis conducted by varying the CONUS-to-forward-storage and forward-storage-to-base legs indicates that savings are reduced as pipeline times increase. Forward storage can be attractive from a strictly Air Force perspective, by creating a one-time savings through lowered base levels (vice the DoD perspective that incurs increased pipeline inventory). However, the total pipeline time of the forward-storage-to-base legs must be lower than that of the direct leg, to achieve lower base levels. Finally, although the primary focus of this study addresses the economic benefits of forward stocking, the operational ramifications of forward stocking must also be considered prior to implementation.

Prepositioning supplies used by forward airbases at a forward storage location in the AOR is a viable alternative to the current practice of shipping items directly from CONUS. An item is economically feasible to forward stock if the annual savings realized by reduced shipping costs exceeds the increased one-time, inventory investment costs within a 5-year period.

Notes

1. Dianna Smith, *Determine Feasibility and Criteria for Forward Stocking Air Force-Managed Items at Defense Logistics Agency Depots*. AFLMA Final Report Number LR200520800, Air Force Logistics Management Agency, Maxwell Air Force Base, Gunter Annex, Alabama, May 2006.
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Jeremy A. Howe, Whirlpool Corporation
Benjamin A. Thoele, FitWit Foundation
Major Scotty A. Pendley, USAF
Major Anthony F. Antoline, USAF
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Beyond Authorized versus Assigned: Aircraft Maintenance Personnel Capacity

Most would agree that aircraft maintenance has been and continues to be a challenging, complex task involving a delicate balance of resources to include personnel, equipment, and facilities. This balancing act occurs in a very hectic environment. The Air Force flies 430 sorties per day in support of Operation Iraqi Freedom and Enduring Freedom. A mobility aircraft takes off somewhere in world approximately every 90 seconds.[1] As the demand for aircraft continues to grow, the number of Airmen who support these aircraft is declining. "Since 2001 the active duty Air Force has reduced its end-strength by almost 6 percent but our deployments have increased by at least 30 percent, primarily in support of the Global War on Terror."[2] This reduction in personnel is part of the Air Force's process of drawing down the total force by approximately 40,000 people, with many of these cuts in aircraft maintenance career fields. Also adding to the growing maintenance workload is an aircraft fleet which now averages almost 24 years old, with the average age still increasing.[3]

When it comes to aircraft maintenance, the Air Force depends on metrics to know whether or not we are measuring up to standards. Several metrics exist which attempt to measure the success or failure of our maintainers' efforts. One of the most recognized metrics is the total not mission capable maintenance (TNMCM) rate. Air Force Instruction 21-101 describes TNMCM as "perhaps the most common and useful metric for determining if maintenance is being performed quickly and accurately."[4] Although a lagging type indicator, it is one of several key metrics followed closely at multiple levels of the Air Force. Over the last several years, the TNMCM rate for many aircraft gradually increased. This fact was highlighted during a 2006 quarterly Chief of Staff of the Air Force Health of the Fleet review. Follow-on discussions ultimately resulted in the Air Force Materiel Command Director of Logistics (AFMC/A4) requesting the Air Force Logistics Management Agency (AFLMA) to conduct an analysis of TNMCM performance with the C-5 Galaxy aircraft as the focus. AFLMA conducted two studies in support of this request.

Beyond Authorized versus Assigned: Aircraft Maintenance Personnel Capacity

To meet this objective, a new factor designated as net effective personnel (NEP) was developed. NEP articulates available maintenance capacity in a more detailed manner that goes beyond the traditional authorized versus assigned personnel viewpoint.

Background

The *C-5 TNMCM Study II* (AFLMA project number LM200625500) included five objectives. One of those objectives was to determine root causes of increasing TNMCM rates for the C-5 fleet. An extensive, repeatable methodology was developed and utilized to scope an original list of 184 factors down to two potential root causes to analyze in-depth for that particular study. These two factors were aligning maintenance capacity with demand, and the logistics departure reliability versus TNMCM paradigm. To address the root cause factor of aligning maintenance capacity with demand, a method of determining available maintenance capacity was needed. To meet this objective, a new factor designated as net effective personnel (NEP) was developed. NEP articulates available maintenance capacity in a more detailed manner that goes beyond the traditional authorized versus assigned personnel viewpoint. The remainder of this article describes the need for NEP and how the NEP calculations were developed during the *C-5 TNMCM S*tudy II. The NEP calculations were ultimately used in conjunction with historical demand to propose base-level maintenance capacity realignments resulting in projected improvements in the C-5 TNMCM rate.

Personnel as a Constraint

The analytical methodology applied to the C-5 maintenance system determined that personnel availability was an important factor to consider. This idea is not new; indeed, the force-shaping measures underway in the Air Force have brought the reality of constrained personnel resources to the forefront of every airman's mind. Without exception, maintenance group leadership (MXG) at each base visited during the C-5 TNMCM Study II considered personnel to be one of the leading constraints in reducing not mission capable maintenance hours. The study team heard the phrase "we need more people" from nearly every shop visited:

> *"The biggest problem for the maintainers here is a shortage of people."*[5]

> *"With more people we could get a higher MC [mission capable]. We're currently just scrambling to meet the flying schedule."*[6]

> *"Hard-broke tails and tails in ISO [isochronal inspection] get less priority than the flyers. We run out of people—we physically run out."*[7]

The Air Force defines total maintenance requirements (authorizations) on the basis of the Logistics Composite Model (LCOM) and current manpower standards. LCOM is a stochastic, discrete-event simulation which relies on probabilities and random number generators to model scenarios in a maintenance unit and estimate optimal manpower levels through an iterative process. The LCOM was created in the late 1960s through a joint effort of RAND and the Air Force Logistics Command.

Though intended to examine the interaction of multiple logistics resource factors, LCOM's most important use became establishing maintenance manpower requirements. LCOM's utility lies in defining appropriate production levels, but it does not differentiate experience.[8] Once these requirements are defined, the manpower community divides these requirements among the various skill levels as part of the programming process. Overall, the manpower office is charged with determining the number of slots, or spaces, for each skill level needed to meet the units' tasks. The personnel side then finds the right *faces*, or people, to fill the spaces.

One measure historically used to quantify personnel availability is the ratio between authorized and assigned personnel. While this ratio is an indicator of maintenance capacity, it provides only a limited amount of information. Authorized versus assigned ratios do not take into account the abilities and skill levels of the maintenance personnel, nor does it factor in the availability of the personnel on a day-to-day basis. These issues were addressed in the *C-5 TNMCM Study II* by quantifying "we need more people" beyond the traditional metric of authorized versus assigned personnel. This capacity quantification was done as part of the larger effort of aligning capacity with demand. The process of capacity planning generally follows three steps:

- Determine available capacity over a given time period
- Determine the required capacity to support the workload (demand) over the same time period
- Align the capacity with the demand[9]

The following describes how the study team pursued step 1, determining available capacity over a given time period, using data from the 436 MXG at Dover Air Force Base (AFB) and characterizing the results in terms of what the study team denoted as NEP.

Determining Available Capacity

When personnel availability and capacity are discussed at the organizational level, typically the phrase *authorized versus assigned* personnel is used. However, are all people assigned to maintenance organizations—namely, an aircraft maintenance squadron (AMXS) or a maintenance squadron (MXS)—viable resources in the repair process? Most maintainers will answer no. While it is true that all assigned personnel serve a defined and important purpose, not everyone in these organizations is a totally viable resource to be applied against maintenance demand. This impacts maintenance repair time and aircraft availability.

TNMCM time begins and ends when a production superintendent advises the maintenance operations center to change the status of an aircraft. The length of that time interval is determined by several things. One factor is the speed of technicians executing the repair, which includes diagnosis, corrective action, and

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Beyond Authorized versus Assigned: Aircraft Maintenance Personnel Capacity

The distinction of nonmanager 7-levels generally reflects 7-levels in the grades of E-5 and E-6. In active duty units, 7-levels in the grade of E-7 do not typically perform hands-on aircraft maintenance, but are instead directors of resources and processes—they are managers.

testing (illustrated in Figure 1) the repair node of Hecht's *restore-to-service* process model.

As illustrated by the Hecht process model, there are other important components required to return an aircraft to service, but the pool of manpower resources required to support the repair node is critically linked to TNMCM time. Within a mobility

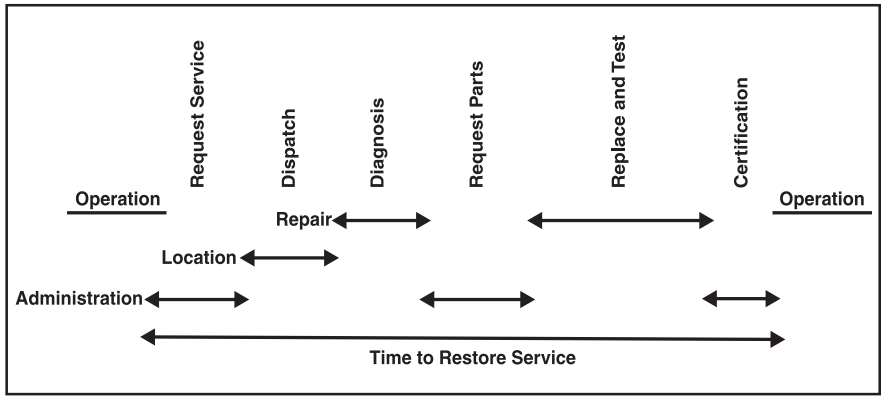

Figure 1. Time to Restore Service Process Model[10]

aircraft maintenance organization, this pool represents hands-on 2AXXX technicians whose primary duty is performing aircraft maintenance. Specifically, the study team defined the technician resource pool as follows:

> **Technicians**: the collective pool of Airmen having a 2AXXX AFSC, that are 3-level or 5-level maintainers, or nonmanager 7-level maintainers whose primary duty is the hands-on maintenance of aircraft and aircraft components.

The distinction of nonmanager 7-levels generally reflects 7-levels in the grades of E-5 and E-6. In active duty units, 7-levels in the grade of E-7 do not typically perform hands-on aircraft maintenance, but are instead directors of resources and processes—they are managers.[11] This is in stark contrast to Air National Guard units, where 2AXXX personnel in the senior noncommissioned officer ranks routinely perform *wrench-turning*, hands-on maintenance.[12] For the research detailed in the *C-5 TNMCM Study II*, personnel analysis centered on data from the 436 MXG at Dover AFB and utilized the study team's definition of technicians.

Net Effective Personnel

Authorized versus assigned personnel figures usually quantify the entire unit. With the definition of technicians in mind, it is important to consider three additional factors that introduce variability into the personnel resource pool. These factors are as follows:

- Skill-level productivity

- Ancillary and computer-based training (CBT)
- Availability

The study team examined the influence of these three factors, as well as their impact on the viable resource pool for the 436 MXG. This collective impact yielded a new resource pool representing a depiction of *effective* capacity rather than just the authorized versus assigned ratio. Again, this new resource pool is denoted as Net Effective Personnel, or NEP.

Factor 1: Skill-Level Productivity

In order to accurately examine the quantitative adequacy of a resource, as well as how a resource has historically been used to meet demand, there must be parity among individual resource units. Consider the previous definition of technicians. If one were to select two people at random, would they be equally capable resources? Not necessarily, if one was a 3-level trainee and the other was a 5 or 7-level resource. In order to collectively examine people in terms of comparable resources, and to account for the skill-level variability in typical aircraft maintenance organizations, productivity factors were applied to the resource pool.

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As part of this research effort, the study team utilized its strategic partnership with RAND Project Air Force. Through personal interviews with RAND personnel and review of recently published RAND research, the study team learned that RAND had explored the productivity of trainees and trainers in aircraft maintenance units. Trainees were defined as 3-levels, who are not as productive as 5- and 7-levels. Additionally, some 5- and 7-levels were not as productive as others because they spend time training and instructing 3-level personnel.[13] In terms of specific productivity based on RAND research, 3-levels were estimated to be 40 percent productive, 5-level trainers and nonmanager 7-level trainers were estimated to be 85 percent productive, and 5-levels and nonmanager 7-levels were 100 percent productive if they were unencumbered with training responsibilities.[14] For the purpose of this analysis, the number of trainers was considered to be equal to the number of 3-levels assigned—a one-to-one ratio. The productivity factors for the viable resource pool are summarized in Table 1.

These productivity factors also are similar to results from additional RAND research at Travis AFB published in 2002.[16] Considering the productivity factors from Table 1, the net effect of these productivity factors alone was a reduction of the 436 AMXS viable resource pool by an average of 5.68 percent.[17]

Technician Category	Productivity Factor
Non-manager 7-levels	100%
Non-manager 7-level trainers	85%
5-levels	100%
5-level trainers	85%
3-levels	40%

Table 1. Productivity Factors[15]

Factor 2: Ancillary Training and Computer-Based Training

In recent times the impact of ancillary training and CBT has been such an important issue for Air Force senior leaders, that it was the sole topic of the airman's Roll Call

Beyond Authorized versus Assigned: Aircraft Maintenance Personnel Capacity

One unit training manager explained that in the past, a group training briefing would be conducted for an entire work center, fulfilling each individual's training requirement simultaneously. Today, an online course issues the required certificate of completion for only one individual, thereby necessitating that each airman conduct the training individually. The net result is more time away from primary duties (for example, repairing aircraft). In order to assess the influence of ancillary training and CBT on the technician resource pool, the study team quantified the average daily impact.

of 9 February 2007.[18] This document indicated that some active duty Airmen spend disproportionate amounts of time on ancillary training, which detracts from their ability to perform official duties. Moreover, the document suggested that some ancillary training may no longer be relevant.[19] In the context of the viable pool of aircraft maintenance technicians, this would mean that, some of the time, personnel resources may be on duty but unavailable to perform hands-on maintenance due to an ancillary training requirement.

A consensus majority of personnel interviewed during the study team's site visits echoed these concerns, describing an *insidious growth* of new training requirements in recent years.[20] An additional concern voiced by interviewees pertained to computer resources. Interviewees described a situation where office workers have ready access to a personal computer (PC), but dozens of maintenance technicians often share only a handful of communal PCs. Consequently, their ability to complete computer-based ancillary training is constrained. One unit training manager explained that in the past, a group training briefing would be conducted for an entire work center, fulfilling each individual's training requirement simultaneously.[21] Today, an online course issues the required certificate of completion for only one individual, thereby necessitating that each airman conduct the training individually. The net result is more time away from primary duties (for example, repairing aircraft). In order to assess the influence of ancillary training and CBT on the technician resource pool, the study team quantified the average daily impact.

A list of various ancillary and computer-based training items that are applicable to the relevant pool of aircraft maintenance personnel was collected from three data sources:

- The USAF Education and Training Course Announcement (ETCA) Web site[22]
- The unit training monitor at the AFLMA
- The unit training monitor for the 105 MXG at Stewart Air National Guard Base (ANGB)

The training was categorized by data source, course number (if applicable), and course name. Training was also categorized as follows.

- Mandatory for all personnel, such as law of armed conflict training
- Voluntary or job-specific, such as hazardous material management training

Also, requirements were identified by the recurrence frequency (one-time, annual, or semiannual). Some requirements are aligned with the 15-month aerospace expeditionary force cycle; this would equate to a yearly recurrence frequency of 0.8 (12/15). Finally, training was categorized by the duration in hours for each requirement as identified by the data sources.

Most training courses only take up a portion of the duty day. The average duration for courses considered was 2.8 hours, with many listed at one hour or less. In situations

like these, a manager would still view the individual as *available* for the duty day.[23] Therefore, the study team examined the impact of CBT and ancillary training as a separate factor and not as a part of the availability factor (factor 3). Final calculations resulted in the following totals:

- Hours of mandatory one-time training (denoted M_o), 101.5 hours
- Hours of mandatory annually-recurring training (M_a), 67.2 hours
- Voluntary or job-specific one-time training (VJS_o), 85.8 hours
- Voluntary or job-specific annually-recurring training (VJS_a), 10.3 hours

In order to quantify the daily impact of these training items, the study team made the following assumptions:

- An 8-hour workday
- 220 workdays in a calendar year. (5 days per week x 52 weeks per year) = 260; 260 – (30 days annual leave) – (10 federal holidays[24]) = 220 workdays.
- 3-levels required all of the mandatory, one-time training.
- 5-levels and 7-levels required only the annually-recurring portion of the mandatory training.
- As an average, all 3-levels required 10 percent of the voluntary or job-specific, one-time training.
- As an average, all 5-levels and 7-levels required 10 percent of the voluntary or job-specific, one-time, annually-recurring training.
- As an average, all training durations would be increased 20 percent to account for travel, setup, and preparation.[25]

When employing the above assumptions, the figures in Table 2 were calculated to be best estimates of the time impact of ancillary training and CBT.

The best estimates for CBT and ancillary training requirements account for 7.51 percent and 5.24 percent of the workday for 3-, 5-, and 7-levels, respectively.

The best estimates for CBT and ancillary training requirements account for 7.51 percent and 5.24 percent of the workday for 3-, 5-, and 7-levels, respectively. The complementary effectiveness rates for this factor are expressed as 0.9249 (1 – 0.0751) for 3-levels and 0.9476 (1 – 0.0524) for 5 and 7-levels. These rates are listed as the ancillary and CBT factors for 3-, 7-, and 5-levels respectively in Table 6.

Technician	Hours per Year	Hours per Workday	Percentage of 8-Hour Workday	Minutes per Workday
3-level	132.10	0.60	7.51%	36.03
Formula	$1.2(M_o+(0.1VJS_o))$	(Hrs/yr)/220	(Hrs/workday/8)*100	(Hrs/workday)*60
5- / 7-level	92.17	0.42	5.24%	25.1
Formula	$1.2(M_a+(0.1(VJS_o+VJS_a))$	(Hrs/yr)/220	(Hrs/workday/8)*100	(Hrs/workday)*60

Table 2. Best Estimate of CBT and Ancillary Training Time Requirements

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Table 3 illustrates how these rates change when the percentages of voluntary and job-specific training (V/JST) or the percentage of travel and setup buffer are varied. The matrices in Table 3 illustrate the results of sensitivity analysis of various CBT and ancillary training factors that would result for combinations of voluntary or job-specific training, or travel and setup buffer ranging from zero to 25 percent. The range of all calculated factors is approximately 3 percent for both technician categories. Note that the CBT and ancillary training factors chosen utilizing the study team's assumptions are boxed and shaded. For both 3-, 5-, and 7-levels, the calculated training factors fall very near the mean developed in the sensitivity analysis. Some values shown in Table 3 are the result of rounding. For the 436 MXG at Dover AFB, the net effect of these CBT and ancillary training factors alone was a reduction of the viable resource pool by an average of 1.58 percent.[26]

Factor 3: Availability

Manpower resources must be present to be viable, and on any given day, aircraft maintenance organizations lose manpower resources due to nonavailability. Examples include temporary duty (TDY) assignments, sick days, and other details. To illustrate, Figure 2 depicts the actual availability of 436 AMXS airframe and powerplant general (APG) technicians on day shift for Thursday, April 12, 2007. For this work center, on this particular day and shift, roughly 65 percent of assigned technicians were not available for the various reasons listed.

Much like aircraft maintenance, some events that take people away from the available pool are scheduled and known well in advance, while others are unexpected, such as illnesses and family emergencies.

Although scheduled and unscheduled events both have an impact, scheduled events are anticipated and can be planned for. Adjustments can be made and resources can be shifted. Consequently, resource managers want to monitor and manage scheduled personnel nonavailability to the greatest extent possible. In order to assess the impact of this factor on the resource pool, the study team monitored the personnel availability of the 436 AMXS at Dover AFB from 1 March through 30 April 2007 via 9 weekly snapshots. 436 AMXS supervision tracks manpower via a spreadsheet tool that identifies the availability status of each assigned 3-level, 5-level, and nonmanager 7-level in their hands-on maintenance resource pool. For AMXS, this represents technicians from six different shops, identified with the corresponding Air Force specialty codes (AFSC) as follows:

- Airframe and Powerplant General (APG) – 2A5X1C, 2A5X1J
- Communication and Navigation (C/N) – 2A5X3A
- Electro/Environmental Systems (ELEN) – 2A6X6
- Guidance and Control (G/C)[28] – 2A5X3B
- Hydraulics (HYD) – 2A6X5
- Engines (JETS) – 2A6X1C, 2A6X1A

3-Levels						
	% Travel/Setup Multiplier					
% V/JST	1	1.05	1.1	1.15	1.2	1.25
0.00	0.942	0.939	0.937	0.934	0.931	0.928
0.05	0.940	0.937	0.934	0.931	0.928	0.925
0.10	0.937	0.934	0.931	0.928	**0.925**	0.922
0.15	0.935	0.932	0.929	0.925	0.922	0.919
0.20	0.933	0.929	0.926	0.922	0.919	0.916
0.25	0.930	0.927	0.923	0.920	0.916	0.913
5- and 7-Levels						
	% Travel/Setup Multiplier					
% V/JST	1	1.05	1.1	1.15	1.2	1.25
0.00	0.962	0.960	0.958	0.956	0.954	0.952
0.05	0.959	0.957	0.955	0.953	0.951	0.949
0.10	0.956	0.954	0.952	0.950	**0.948**	0.945
0.15	0.954	0.951	0.949	0.947	0.944	0.942
0.20	0.951	0.948	0.946	0.944	0.941	0.939
0.25	0.948	0.946	0.943	0.940	0.938	0.935
Descriptive Statistics						
	Mean	**Min**	**Max**	**Range**		
3-Level	0.928	0.913	0.942	0.030		
5- and 7-Level	0.949	0.935	0.962	0.027		

Table 3. CBT and Ancillary Training Factor Sensitivity Analysis

		3-Level	5-Level	7-Level	Total	% of Total
Reason Unavailable	**Assigned**	32	28	22	82	100%
	Temporary Duty		6	4	10	12%
	Qualification and Training Program	9			9	11%
	Detail	2	3	2	7	9%
	Leave	2	3	2	7	9%
	Scheduled Off Day	2	1	2	5	6%
	Medical Profile		2	1	3	4%
	Part-day Appointment	1	1	1	3	4%
	Full-day Appointment			2	2	2%
	Compensatory Off Day			1	1	1%
	Flying Crew Chief Mission		1		1	1%
	Out Processing		1		1	1%
	Permanent Change of Assignment		1		1	1%
	Field Training Detachment Course		1		1	1%
	First Term Airmen's Center	1			1	1%
	Bay Orderly	1			1	1%
	Available	14	8	7	29	35%

Figure 2. 436 AMXS APG Day Shift Personnel Availability Snapshot[27]

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The NEP figures account for the realities of availability and productivity, and allow the resource pool to be viewed objectively, unconstrained by concerns such as skill-level differences. The value of such a resource picture is that it provides a suitable mechanism for comparing maintenance capacity (NEP resource pool) with maintenance demand.

The AMXS snapshot spreadsheet is updated (but overwritten) continually as status changes occur.[29] By monitoring changes in these snapshots, the study team was able to examine not only the impact of personnel nonavailability in aggregate, but also the degree to which the discovery and documentation of events altered the size of the capacity pool. Using the Dover AMXS snapshots, the study team calculated the number of available technicians in the aircraft maintenance resource pool.

The study team monitored the actual availability figures for the 436 AMXS over the 9-week period of March and April 2007, for a total of $n = 61$ daily observations. Across all shifts, the total number of personnel assigned to the AMXS personnel resource pool was 411 for the month of March, and 412 for the month of April. Actual availability figures, however, were much lower. Table 4 summarizes the descriptive statistics of this analysis.

The upper row of Table 4 statistics reflects the actual number of technicians available, while the bottom row reflects that number as a percentage relative to the total number of technicians assigned. For example, in the month of March, the maximum number of available technicians observed was 202, or 49 percent (202 of 411) of the total assigned. The mean availability for March was 36 percent. These figures take into consideration that some of the nonavailable personnel may be performing duties elsewhere for the Air Force such as flying crew chief missions or other TDY assignments. Therefore, they would not be viable assets for the aircraft maintenance resource pool at Dover AFB. The net effect of this nonavailability factor was a reduction of the AMXS home station viable resource pool by an average of 65.39 percent. This is reflected as the 35 percent mean highlighted for March-April 2007.

As discussed previously with Factors 1 and 2, the productivity of available technicians is reduced due to skill-level training needs, as well as ancillary and CBT training requirements. The study team applied productivity factors from Table 1 and CBT and ancillary training factors from Table 2 to the observed number of available technicians in AMXS. These calculations quantified the final pool of viable personnel resources, which is denoted as NEP. Because of daily variations in the number of 3-, 5-, and 7-skill level technicians available, the factors were applied to each daily observation. In performing these calculations, the study team developed a representation of the effective personnel resource pool. Specifically, the NEP figures account for the realities of availability and productivity, and allow the resource pool to be viewed objectively, unconstrained by concerns such as skill-level differences. The value of such a resource picture is that it provides a suitable mechanism for comparing maintenance capacity (NEP resource pool) with maintenance demand. The summary descriptive statistics for the 436 AMXS NEP are indicated in Table 5. Averaging across the observed timeframe, the 436 AMXS had approximately 113 net effective technicians in its viable resource pool on any

given day. This figure is approximately 27 percent of the total assigned quantity of technicians, again using the previously discussed definition for technicians.

Therefore, to arrive at the results shown in Table 5, the study team considered the factors from Table 1 and 2, as well as the ancillary and CBT factors complimentary effectiveness rates calculated.

Each factor and rate detailed to this point was assigned a new designation for ease of use in the proposed NEP equation. The newly designated factors, factor descriptions, and the associated values are listed in Table 6.

The *T* factors relate to training, the *A* factors relate to available personnel, and the *P* factors relate to productivity. These factors were applied to the number of available technicians as recorded in the AMXS availability snapshots using the newly proposed NEP calculation, shown as Equation 1. Equation 1 is the cumulative NEP equation which accounts for all three factors which create variability in the resource pool and yields a numerical quantity of net effective personnel. To determine the NEP percentage, one need simply divide the right side of the equation by the number of assigned technicians (7-level nonmanagers, 5-levels, and 3-levels).

Figure 3 provides an Excel spreadsheet snapshot of an example NEP calculation for a generic maintenance unit. The maintenance unit's NEP is calculated using Equation 1 by entering the personnel totals in each of the five categories in the left column. These values are then multiplied by the factors in the right column to

411 Assigned	March 07				April 07				March-April 07			
	Min	Max	Mean	Range	Min	Max	Mean	Range	Min	Max	Mean	Range
Available	100	202	**147**	102	104	163	**137**	59	100	202	**142**	102
% of Assigned	24%	49%	**36%**	25%	25%	40%	**33%**	14%	24%	49%	**35%**	25%

Table 4. 436 AMXS Availability Descriptive Statistics

411 Assigned	March 07				April 07				March-April 07			
	Min	Max	Mean	Range	Min	Max	Mean	Range	Min	Max	Mean	Range
Available	79	167	**120**	88	77	124	**105**	47	77	167	**113**	90
% of Assigned	19%	41%	**29%**	21%	19%	30%	**26%**	11%	19%	41%	**27%**	22%

Table 5. 436 AMXS NEP Descriptive Statistics

Factor	Description	Value
T_{75}	Ancillary/CBT Factor for 7- and 5-levels	0.948
A_{75NT}	The number of available nonmanager 7-levels and 5-levels who are not trainers	Varies day-to-day
P_t	Trainer Productivity	0.85
A_{75T}	The number of available nonmanager 7-levels and 5-levels who are trainers	Varies day-to-day
T_3	Ancillary/CBT Factor for 3-levels	0.925
P_e	Trainee Productivity	0.4
A_3	The number of available 3-levels	Varies day-to-day

Table 6. NEP Factors

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determine NEP. In this example, the unit has 104 technicians available but the NEP is only 77. In other words, the practical available maintenance capacity is only 77 technicians, not 104 as it initially appears.

To summarize, the study team's arrival at NEP followed an iterative sequence of three factor reductions:

- Skill-level productivity differences, to include those for trainees and trainers
- Ancillary training and CBT
- The nonavailability of personnel

Figure 4 graphically illustrates these iterations based on the relative size of the impact of the three factors on reductions to the overall resource pool. As shown in Figure 4, nonavailability had the biggest impact, productivity factors were next, and finally the effect of CBT and ancillary training had the smallest impact.

$$NEP = T_{75}(A_{75NT} + (P_t A_{75T})) + T_3(P_e A_3)$$

Equation 1. Net Effective Personnel

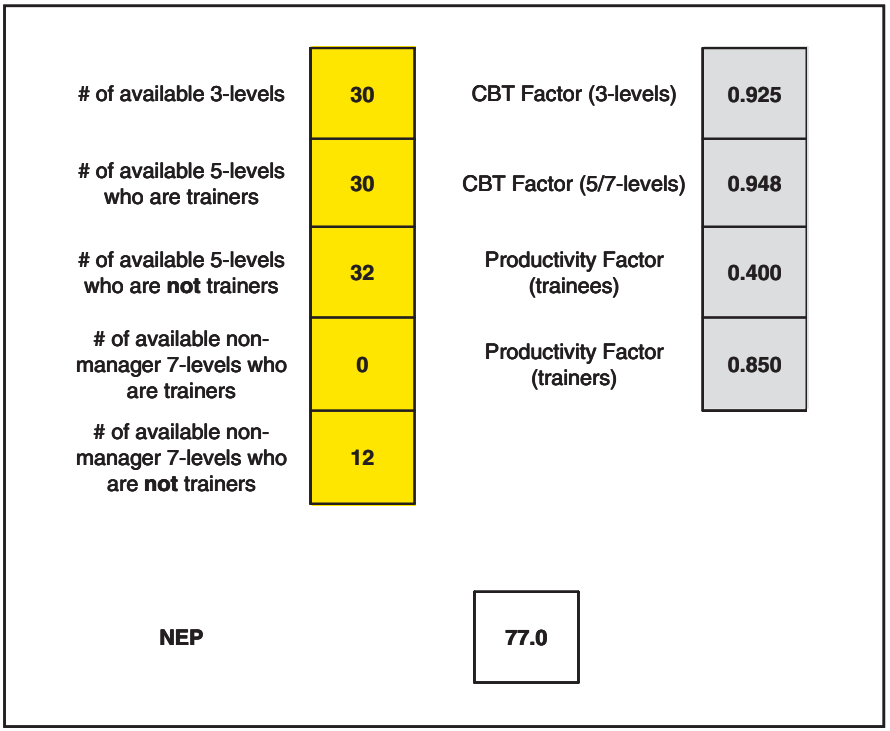

Figure 3. Example NEP Calculation

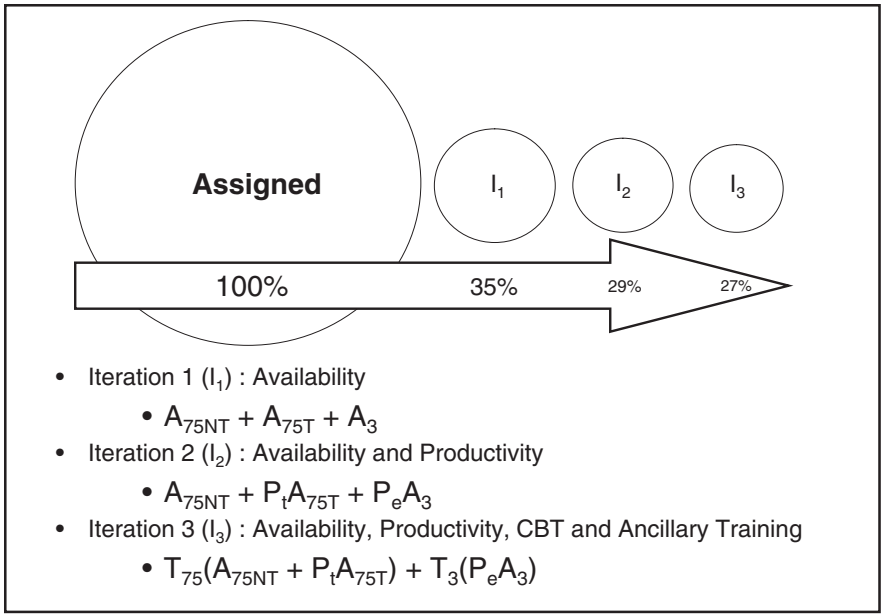

Figure 4. The Iterations of NEP

In addition to AMXS, an Air Force Maintenance Group usually includes a separate equipment maintenance squadron (EMS) and component maintenance squadron (CMS). However, if total authorizations are under 700, EMS and CMS will be combined into a maintenance squadron such as the MXS at Dover AFB. Various flights within a typical MXS maintain aerospace ground equipment, munitions, off-equipment aircraft and support equipment components; perform on-equipment maintenance of aircraft and fabrication of parts; and provide repair and calibration of test, measurement, and diagnostic equipment.[30] Technicians assigned to MXS usually perform maintenance not explicitly linked to the launch and recovery of aircraft (as is the focus of AMXS). However, some MXS personnel directly support flight line activities.

A more complete representation of the net effective personnel pool for aircraft maintenance resources in an MXG would include not only personnel in AMXS, but also those in MXS. The number of nonmanager 7-levels, 5-levels, and 3-levels assigned to the 436 MXS was determined from Air Force Personnel Center data to be 318.[31] Using the study team's definition of technician, this results in 729 technicians in the 436 MXG (411 in AMXS plus 318 in MXS). However, because the study team could not obtain exact daily availability figures for MXS similar to those of AMXS, the study team applied each of the calculated daily NEP percentages for AMXS against the number of assigned technicians to MXS. This calculation yielded daily estimates of the number of NEP for MXS. Since AMXS

Beyond Authorized versus Assigned: Aircraft Maintenance Personnel Capacity

The ratio between authorized and assigned personnel is typically used to quantify personnel availability. While this ratio is an indicator of maintenance capacity, it provides only a limited amount of information.

and MXS are both aircraft maintenance units with many of the same AFSCs and similar demands on their personnel, any differences from actual numbers as a result of this method were considered negligible for this analysis.

The study team then added the AMXS NEP figures to the MXS NEP figures, resulting in a collective NEP figure for the flight line maintainers at Dover AFB. These collective NEP figures are shown in Table 7. The upper portion of the table shows the NEP figures grouped by columns (day of the week) with each row representing 1 of the 9 weeks over the entire period that data was tracked. The bottom section of Table 7 also displays the descriptive statistics for NEP across both AMXS and MXS combined. The highest average NEP value was 222 on Thursdays, representing approximately 30 percent of the baseline total of 729 people.

Conclusion

The ratio between authorized and assigned personnel is typically used to quantify personnel availability. While this ratio is an indicator of maintenance capacity, it provides only a limited amount of information. These ratios do not take into account the abilities and skill levels of the maintenance personnel, nor does it factor in the availability of the personnel on a day-to-day basis. The Net Effective Personnel methodology described in this article is a repeatable process which produces NEP figures that provide leadership with a better representation of the personnel resources

	Day of the Week NEP Distributions						
	Sun	Mon	Tue	Wed	Thu	Fri	Sat
NEP	186	219	228	211	259	219	187
	148	209	226	219	213	182	140
	153	212	211	242	219	195	155
	188	242	289	297	245	205	169
	165	210	220	216	294	235	198
	137	186	187	195	205	175	148
	173	206	192	188	194	176	168
	167	213	201	195	183	186	174
	176	203			185	194	180
n	9	9	8	8	9	9	9
Min	137	186	187	188	183	175	140
Max	188	242	289	297	294	235	198
Mean	166	211	219	221	222	196	169
% of Assigned	23%	29%	30%	30%	30%	27%	23%
Range	51	56	102	109	110	59	58
Variance	300	221	1031	1241	1385	404	349
Standard Dev	17	15	32	35	37	20	19

Table 7. Day of the Week NEP Distributions for 436 MXG (AMXS and MXS)[32]

and actual capacity available to an Air Force aircraft maintenance organization on a day-to-day basis. The NEP methodology will be tested further and validated using personnel data from other units to verify similar results and potential gains. Ultimately, the NEP methodology has the potential to be used alone or in conjunction with LCOM to better portray maintenance personnel requirements and capabilities based on experience and skill levels.

As previously mentioned, the NEP methodology described in this article was developed as part of the larger *C-5 TNMCM Study II*. The entire study can be found at the Defense Technical Information Center Private Scientific and Technical Information Network Web site at https://dtic-stinet.dtic.mil/.

The Net Effective Personnel methodology described in this article is a repeatable process which produces NEP figures that provide leadership with a better representation of the personnel resources and actual capacity available to an Air Force aircraft maintenance organization on a day-to-day basis.

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30. *Ibid*.
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32. Values in Table 7 are rounded to nearest whole number.

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Aligning Maintenance Metrics: Improving C-5 TNMCM

Metrics are often used as roadmaps to help us know where we have been, where we are going, and how or if we are going to get there.[1] Metrics should generally be used to gauge organizational effectiveness and efficiency and to identify trends, not as a pass or fail indicator. Individually, they are snapshots in time.[2] Metrics are a statement of what is important to your organization and embody a way of thinking about your business; when metrics change, so does people's point of view. But what exactly is a metric and what constitutes a good versus bad metric?

Air Force Instruction (AFI) 21-101, *Aircraft Equipment and Maintenance Management,* describes metrics, specifically maintenance management metrics, as a crucial form of information used by maintenance leaders to improve the performance of maintenance organizations, equipment, and people when compared with established goals and standards.[3] AFI 21-101 also lists four attributes for metrics including:

- Accurate and useful for decisionmaking
- Consistent and clearly linked to goals and standards
- Clearly understood and communicated
- Based on a measurable, well-defined process[4]

Dr Michael Hammer, a recognized leader in the field of process reengineering, also notes four principles of measurement.

- Measure what matters, rather than what is convenient or traditional
- Measure what matters most, rather than everything
- Measure what can be controlled, rather than what cannot be controlled
- Measure what has impact on desired business goals, rather than ends in themselves[5]

Aligning Maintenance Metrics: Improving C-5 TNMCM

The C-5 TNMCM Study II included five objectives. One of those objectives was to determine root causes of increasing TNMCM rates for the C-5 fleet. To achieve that particular objective, an extensive, repeatable methodology was developed and utilized to scope an original list of 184 TNMCM factors down to two root causes for in-depth analysis. Those two factors were aligning maintenance capacity with demand and the logistics departure reliability (LDR) versus TNMCM paradigm.

Hammer also points out several flaws with traditional metrics such as too many, fragmented, disorganized, internally focused, irrelevant to the customer, not used systematically, and not aligned with goals.[6] It is this last flaw (metrics not aligned with goals) which became a focus of examination during an Air Force Logistics Management Agency (AFLMA) study of rising Air Force total not mission capable maintenance (TNMCM) rates and potential root cause factors affecting these rates.

Background

This article is the second of a three-part series based on AFLMA project number LM200625500, the *C-5 TNMCM Study II*. At the request of the Air Force Materiel Command Director of Logistics (AFMC/A4), AFLMA conducted an analysis in 2006-2007 of TNMCM performance with the C-5 Galaxy aircraft as the focus. The *C-5 TNMCM Study II* included five objectives. One of those objectives was to determine root causes of increasing TNMCM rates for the C-5 fleet. To achieve that particular objective, an extensive, repeatable methodology was developed and utilized to scope an original list of 184 TNMCM factors down to two root causes for in-depth analysis. Those two factors were aligning maintenance capacity with demand and the logistics departure reliability (LDR) versus TNMCM paradigm. This article details the analysis of the second of these two factors.

This second factor was also described as a disconnect or misalignment between the C-5 maintenance group (MXG) leadership's primary metric, home station logistics departure reliability (HSLDR), and one of the major command (MAJCOM) and Air Force senior leadership's primary metrics, aircraft availability (AA). The remainder of this article describes how real-world and simulated data supported the early hypothesis that HSLDR and TNMCM were not aligned metrics. Finally, a brief discussion explains why the study team believed a disconnect existed between the base-level and command-level metrics.

Primary Metrics of C-5 Maintenance Leadership

The *C-5 TNMCM Study II* originated because the project sponsor placed significant importance on TNMCM rates. Based on site visits and feedback from all but one C-5 MXG commander (MXG/CC) or other MXG senior leaders, the study team determined that the primary metric of the MXG/CC was HSLDR. AA, which is directly related to the TNMCM rate, was a primary metric of higher level leadership. Major General McMahon, then AMC director of logistics (AMC/A4), spoke to the study team in December 2006 concerning aircraft availability as the future cornerstone maintenance metric [as opposed to mission capable (MC) rates].[7] Similarly, personnel from the AMC/A4M office stated that aircraft availability is the number one concern for AMC Headquarters as opposed to MC rates.[8]

During site visits to Dover Air Force Base (AFB), Stewart Air National Guard Base, and Westover Air Reserve Base, the study team received feedback from base-level maintenance leadership concerning maintenance metrics. Some of the comments included:

"We don't manage by MC-Rate…we don't chase the numbers. We care about departure reliability, and [the Air Force] should be looking at en route reliability."[9]

"We don't look at the TNMCM rate…numbers aren't the issue. We focus on the mission and the flying schedule."[10]

"What's important? Anything that makes us fly. The metric for the base is departure reliability…Ops isn't happy with a 73 percent LDR."[11]

"MC rate is way down on the list of things we pay attention to…We're currently scrambling to meet the flying schedule. Our priorities go to the scheduled aircraft."[12]

"Our primary metric is LDR."[13]

Based on feedback from AFMC/A4 and AMC/A4 leadership, MXG/CCs at three C-5 bases, and telephone discussions with MXG leadership at other C-5 bases, the study team concluded that the primary metric of the MAJCOM A4 leadership was AA, which includes TNMCM, and that the primary metric of the MXG/CCs was HSLDR.

HSLDR, TNMCM, and AA Defined

AFI 21-101 defines the HSLDR, TNMCM, and AA metrics and their uses. Additional insight on the use of these metrics can be found in the *Metrics Handbook for Maintenance Leaders*.

Home-Station Logistics Departure Reliability (HSLDR) Rate. This is a leading metric used primarily by the Mobility Air Forces (MAF) for airlift aircraft. This delineates down to only first-leg departures of unit-owned aircraft departing home station.[14]

HSLDR Rate (%) = ((# of HS Departures − # of HS Logistics Delays)/# of HS Departures) x 100

Total Not Mission Capable Maintenance (TNMCM) Rate. TNMCM rate is the average percentage of possessed aircraft (calculated monthly or annually) that are unable to meet primary assigned missions for maintenance reasons…. Any aircraft that is unable to meet any of its wartime missions is considered not mission capable (NMC). The TNMCM is the amount of time aircraft are in NMCM [not mission capable maintenance] plus not mission capable both (NMCB) status.[15]

NMCB is mentioned in AFI 21-101 as the percentage of unit-possessed hours that aircraft are not mission capable due to both maintenance and supply.[16]

TNMCM (%) = ((NMCM Hrs + NMCB Hrs)/Unit Possessed Hrs) x 100

TNMCM rate is the average percentage of possessed aircraft (calculated monthly or annually) that are unable to meet primary assigned missions for maintenance reasons…. Any aircraft that is unable to meet any of its wartime missions is considered not mission capable.

Aligning Maintenance Metrics: Improving C-5 TNMCM

A set of metrics is said to be aligned if, with all other variables held constant, improvement in the lower level metric implies improvement of the higher level metrics.

Aircraft Availability (AA) Rate. Aircraft availability is the percentage of a fleet that is in neither depot possessed status nor unit possessed NMC status.[17]

$$AA\ (\%) = (MC\ Hours/Total\ Possessed\ Hrs) \times 100$$

Note that TNMCM rate and AA rate are both part of the family of metrics that relate to aircraft status hours. Also important to remember is that unit possessed aircraft must be in one of four statuses:

- MC (to include partially mission capable for maintenance or supply)
- NMCM
- Not mission capable supply (NMCS)
- NCMB

Therefore, the percentage of MC hours must decrease as the percentage of NMCM, NMCS, and NMCB hours increase.

Metrics at Different Levels of the Organization

One might expect two different levels of an organization to have two different primary metrics. For the Air Force, the focus at the base maintenance level is expected to be on the tasks at hand to execute the mission on a daily basis. However, a strategic focus at the command A4 level is to be expected, looking across the availability of the entire fleet. Consider Dr Michael Hammer's presentation of this phenomenon in Table 1.

The first column in Table 1 lists the various categories across the spectrum of oversight for an organization, ranging from enterprise goals to local activities. The headings in the top row list the range of positions in the hierarchy of jobs within the organization. In general, senior leaders are primarily accountable for setting the vision and strategy across the entire business enterprise. Process owners are responsible for developing and executing operations and processes to support higher strategy, while professionals actually perform specific work tasks through various activities. Consider this same chart in terms of C-5 aircraft maintenance, shown in Table 2. The base-level focus on on-time departure reliability falls within the *operating objective* level, providing ready airplanes for the flying schedule. On the surface, this supports the strategic performance objectives of cargo and passenger delivery. These processes are, after all, at the core of the airlift mission. On-time departure reliability, as a measurement, only considers those airplanes scheduled to fly (departing).[19] TNMCM, on the other hand, is concerned with the categorization of aircraft status, and pertains to all possessed airplanes, regardless of whether or not there is an operational demand.[20] The takeaway here is that the study team's observations of the C-5 aircraft maintenance enterprise supported Dr Hammer's view

presented in Table 1. The study team found that different levels of the C-5 maintenance hierarchy do in fact focus on different primary metrics.

Aligning Metrics

Although it may be common for different organizational levels to focus on different metrics, this split focus can be problematic for the enterprise when the pursuit of goals at the local level is not aligned to goals at the strategic level. That is, pursuit of better performance in one metric could result in suboptimal performance of higher level metrics. When this occurs, the metrics are not aligned. The study team utilized the following definition for aligned metrics:

> **Definition 1 - Aligned Metrics.** A set of metrics is said to be aligned if, with all other variables held constant, improvement in the lower level metric implies improvement of the higher level metrics.

For example, consider the priorities of a trucking company. The company is concerned with a higher level metric, known as a value measure, of increasing profit. The value measurement is in dollars. Shop managers at a truck maintenance facility use a lower level metric, known as a process measure, of reducing repair cycle time. By reducing the repair cycle time, the labor cost per truck is reduced, and each truck is returned to revenue-generating status sooner. All other variables held constant, reduced labor costs and greater numbers of operational trucks increase profit for the company. In this way, improving cycle time implies improvement in profit.[21] By Definition 1, these metrics are aligned.

Now consider the Air Force maintenance metrics of HSLDR rate and TNMCM rate. The base focus on departure reliability may have a direct effect on prioritizing unscheduled maintenance actions to best meet the flying

	Leadership	Process Owner	Professionals
Enterprise Goals	High*	Low	Medium
Strategic Performance	High*	High	Medium
Operating Objectives	Medium	High*	Medium
Process Performance	Medium	High*	High
Activity Performance	Low		High*
* = primary accountability			

Table 1. Accountability and Attention[18]

	AMC/A4	MXG/CC	Technicians
Enterprise Goals – increase aircraft availability, reduce costs	High*	Medium	Low
Strategic Performance – deliver cargo and passengers accurately and on-time	High*	High	Medium
Operating Objectives – provide ready airplanes for the flying schedule	Medium	High*	Medium
Process Performance – isochronal inspections, unscheduled repair process	Medium	High*	High
Activity Performance – inspect and repair airplanes	Low	High	High*
* = primary accountability			

Table 2. Accountability and Attention for C-5 Aircraft Maintenance

Aligning Maintenance Metrics: Improving C-5 TNMCM

In order to test the impact to TNMCM rates of base-level HSLDR-centric maintenance decisionmaking, the AFLMA study team created a discrete event simulation using Arena simulation software.

schedule. This optimization can cause an airplane that is *hard broke* to be prioritized below another airplane in order to get the *less broke* airplane repaired more quickly and readied for the next flight. This decision, while supporting the objective of on-time departure reliability, may actually have a negative effect on the TNMCM rate. If, however, HSLDR and TNMCM were aligned, an improvement to HSLDR would imply an improvement to TNMCM. To investigate the alignment of the HSLDR, TNMCM, and AA metrics, the study team analyzed data from August 2004 through December 2006 for the 436 MXG at Dover Air Force Base (AFB). The 436 Maintenance Operations Squadron (MOS) analysis section provided the data for the HSLDR and TNMCM rates; the source for the AA rates was the Multi-Echelon Resource and Logistics Information Network.

Mathematically, metric alignment implies that two metrics are fairly strongly related. To test the correlation mathematically, the study team employed the correlation coefficient denoted by the symbol ρ (rho). The correlation coefficient is a number between -1 and 1 which measures the degree to which two variables are linearly related and is scaled such that $\rho > 0$ indicates a positive correlation between the variables. A value of $\rho = +1$ implies a perfect correlation with all ordered pairs (points) falling on a straight line with a positive slope. A value of $\rho = -1$ implies a perfect negative correlation with all points on a straight line with a negative slope.[22] For the purposes of this study, the study team partitioned the correlation coefficient values in the following manner:

- $|\rho| \leqslant 0.20$ implies a very weak correlation
- $0.20 < |\rho| \leqslant 0.50$ implies a weak correlation
- $0.50 < |\rho| \leqslant 0.80$ implies a moderate correlation
- $0.80 < |\rho| \leqslant 1.0$ implies a strong correlation

Figure 1 illustrates the relationship between the TNMCM rate and HSLDR rate. If the metrics were aligned, the graph should show evidence of a strong negative correlation. That is, as HSLDR increased, TNMCM would decrease and vice versa. In this case, the scatter plot reveals no definite relationship, appearing more like a *shotgun* spread. For comparison purposes, the least squares regression line for the data is drawn and the line equation is presented. A regression equation allows for the expression of a relationship between two or more variables algebraically. From Figure 1, the correlation coefficient between HSLDR and TNMCM is very weak, with $\rho = -0.15056$. Therefore, improvement of the HSLDR rate does not imply improvement of the TNMCM rate. By the study's definition, HSLDR and TNMCM were not aligned metrics.

Figure 2 illustrates the relationship between the HSLDR rate and AA rate, the primary metric at the MAJCOM A4 level. Again, the plot resembles a shotgun spread, and there is a very weak correlation coefficient with $\rho = 0.072165$. HSLDR and AA do not appear aligned according to the study's definition.

Figure 3 illustrates the relationship between the TNMCM and AA rates. Here, the scatter plot reveals a negative correlation. Likewise, the correlation coefficient

indicates a moderate negative correlation with $\rho = -0.77927$. This evidence supports the idea that TNMCM and AA are aligned according to the study definition. As the TNMCM rate improves (decrease), the AA rate also tends to improve (increase). This result is not surprising since TNMCM and AA are a part of the same family of status-hour metrics.

In summary, Figures 1, 2, and 3 suggest that TNMCM and AA are aligned, and HSLDR is not aligned with either TNMCM or AA. As stated earlier, the MXG/CC's focus on HSLDR as their primary metric, not TNMCM and AA. Therefore, the MXG/CCs and their personnel make decisions about resources and day-to-day operations which impact HSLDR first. Since HSLDR is not aligned with TNMCM and AA, there is no guarantee that TNMCM or AA will improve as a result of the current operations. The MXG efforts, therefore, are not directly aimed at improving TNMCM rates when they are focusing on improving HSLDR rates.

Experimentation Using C-5 Maintenance Priority (MXP) Simulation

In order to test the impact to TNMCM rates of base-level HSLDR-centric maintenance decisionmaking, the AFLMA study team created a discrete event simulation using *Arena* simulation software. The simulation facilitated an analysis of how different maintenance operations could affect the HSLDR and TNMCM rates

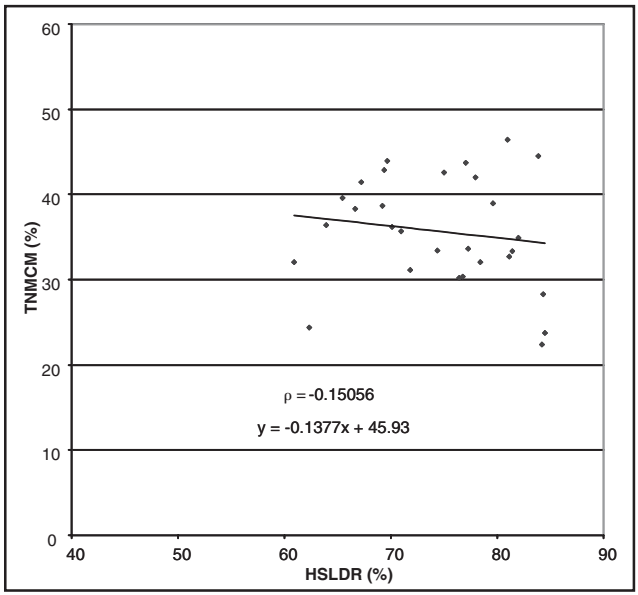

Figure 1. HSLDR and TNMCM Rates Scatter Plot for 436 MXG August 2004 to December 2006

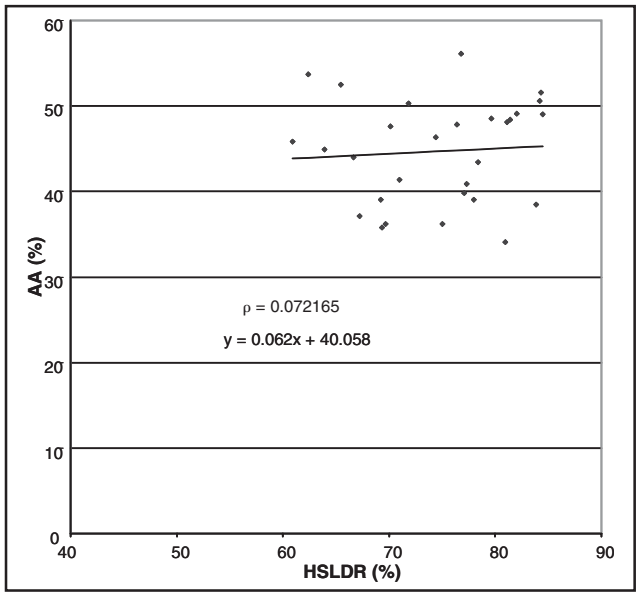

Figure 2. HSLDR and AA Rates Scatter Plot for 436 MXG August 2004 to December 2006

Aligning Maintenance Metrics: Improving C-5 TNMCM

Field interviews conducted by the study team revealed that in order to improve HSLDR, the maintenance commanders gave priority to those aircraft that "have the best chance of being returned to a [fully mission capable] status in minimum time."

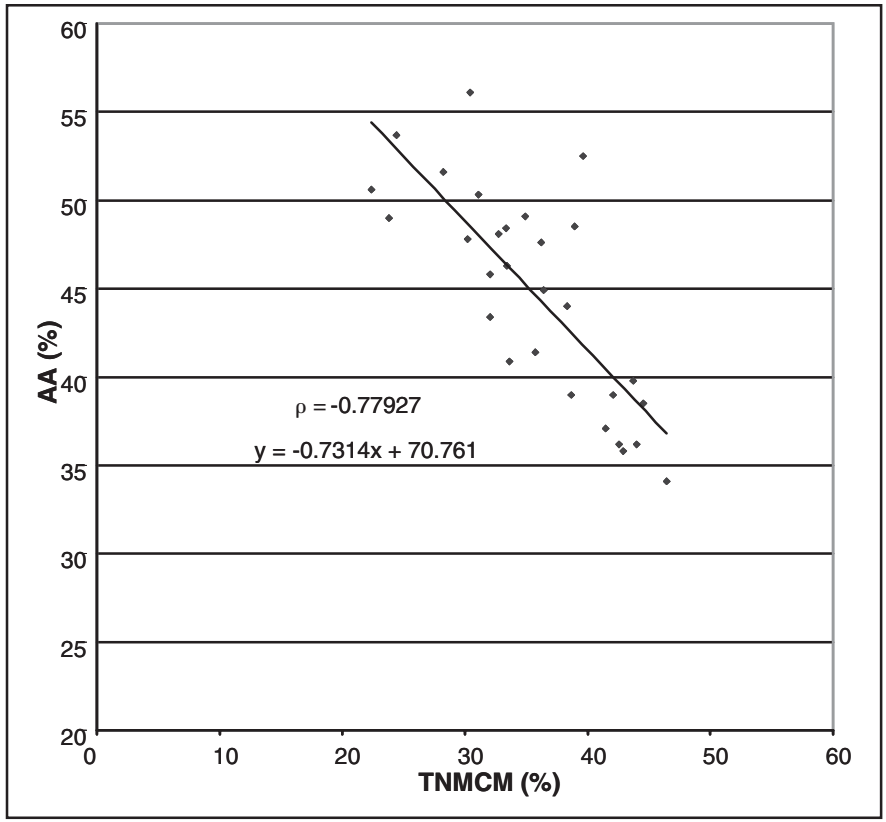

Figure 3. TNMCM and AA Rates Scatter Plot for 436th MXG August 2004 to December 2006

in a controlled environment. This analysis would be impractical to do in the real world. The following sections summarize the development and results of the C-5 maintenance priority (MXP) simulation.

MXP Problem Formulation and Objectives

The MXP model was designed to study the employment of different queuing prioritization policies and their effect on key maintenance performance metrics in the support of C-5 aircraft. These policies determine the order in which aircraft awaiting maintenance are processed. Field interviews conducted by the study team revealed that in order to improve HSLDR, the maintenance commanders gave priority to those aircraft that "have the best chance of being returned to a [fully mission capable] status in minimum time."[23] These *recovery maintenance* practices were utilized at both Travis AFB and Dover AFB for C-5 maintenance.[24] The MXP model labels this as the least maintenance (Mx) policy and determines the priority

of queued aircraft based on the remaining man-hours of repair. Thus, the aircraft with the fewest man-hours of repair remaining relative to other queued aircraft receives top priority when maintenance resources become available. Alternatively, the most Mx policy gives priority to the aircraft with the most man-hours of repair remaining. The two remaining policies are first-in-first-out (FIFO) and last-in-first-out (LIFO). These queuing policies order aircraft according to their arrival. With FIFO, a newly arrived aircraft goes to the back of the queue. In a LIFO policy environment, a newly arrived aircraft goes to the front of the queue.

MXP Data Collection

Data for the MXP came from multiple sources. Aircraft arrival data was provided by the 436 MOS at Dover AFB for the period from January 2006 through March 2007. Manpower data was provided by the 436th Aircraft Maintenance Squadron for March and April 2007. Data for the possessed aircraft inventory, HSLDR rates, and TNMCM rates were provided by the 436 MOS for the fourth quarter fiscal year (FY) 2006. Data for the maintenance processes were taken from the Reliability and Maintainability Information System (REMIS) for fourth quarter FY 2006. The study team determined that these data sets were the most suitable given the availability of data.

MXP Assumptions

Two important assumptions were made in the formulation of the MXP simulation:

- TNMCS time was assumed to have no impact on the maintenance operations or the TNMCM rate. The impact of supply operations was assumed to be accounted for in the repair time data. The MXP does not model any TNMCS time.
- Unit possessed time for all aircraft was assumed to be constant and equal for the four maintenance policies modeled in the MXP simulation.

Data for the MXP came from multiple sources.

MXP Model Conceptualization

The MXP simulation modeled C-5 maintenance operations at Dover AFB. The simulation modeled 18 aircraft (the average number of possessed aircraft for Dover AFB in the fourth quarter FY 2006) that arrive at the base according to a daily arrival schedule with a fixed number of breaks. To achieve the desired arrival stream attributes within the *Arena* simulation framework, the MXP model employed three separate processes.

The first process created 18 C-5 aircraft entities at time zero. The entities then entered an arrival queue at a gate which opens according to the aircraft arrival schedule. Once opened, the gate allowed a single aircraft to proceed to the maintenance process before closing until the next arrival signal was received. The same 18 aircraft entities flowed from arrival process to the maintenance process before being recycled back to the arrival process. In this way, the model never had more than 18 aircraft in the system at one time.

Aligning Maintenance Metrics: Improving C-5 TNMCM

In order to model the parallel and serial nature of aircraft maintenance actions, the study team adopted the repair bin methodology used by Balaban et al., in their mission capable rate simulation model, which they demonstrated using the C-5 fleet.

The second process tracked the day of the week. A clock entity was created at time zero and thereafter stepped through the days of the week at 24-hour intervals. The simulation employed two schedules that depend on the day of the week cycle. The first was related to the maintenance process and defined how many manpower resources were available to perform maintenance on a given day. The second schedule governed the aircraft arrival pattern.

The final process related to aircraft arrivals determined when the gate should be opened allowing an aircraft *to arrive* and proceed to the maintenance process. These triggers were created according to a schedule derived from 15 months of aircraft arrival data at Dover AFB. The data defined day-specific discrete probability distributions of the number of aircraft arrivals. These distributions are given in Table 3.

The manpower resources and repair times required to complete the repairs were drawn from distributions based on the real-world data. The aircraft wait in the maintenance queue until resources are available for repair. Repairs are then completed in three phases.

The values in each row of Table 3 represent the probability of the particular number of arrivals (represented as 0 through 8 in the column headings) on that day of the week. Each row sums to one. These daily arrival distributions are the building blocks for a random aircraft arrival stream based on historic observations at Dover AFB. When all repairs are complete, the manpower resources are released to perform other repairs and the aircraft departs the base.

REMIS data was used to derive a discrete distribution of the number of personnel on a work crew associated with a repair action. Each repair action is assigned a randomly sized crew. Table 4 shows the crew size probability distribution used in the simulation. For example, there is a 0.519 probability that a repair action requires two maintenance personnel. When all repairs are complete, the manpower resources are released to perform other repairs and the aircraft departs the base. The data did not indicate any instances of crew sizes of seven or eight people during the timeframe of the data.

Figure 4 illustrates the overall view of the basic maintenance processes modeled in the MXP.

C-5 arrivals are triggered according to an arrival schedule. After arrival, aircraft require (seize) maintenance resources, maintenance actions are performed, and then manpower resources are released. This cycle is accomplished three times before returning the aircraft to the arrival queue.

In order to model the parallel and serial nature of aircraft maintenance actions, the study team adopted the repair bin methodology used by Balaban et al., in their mission capable rate (MCR) simulation model, which they demonstrated using the C-5 fleet.[25] In reality, certain repair actions are accomplished simultaneously with other repair actions. However, by regulation, some actions cannot be performed simultaneously with certain other maintenance actions. Balaban et al., modeled this

parallel and serial operation by grouping repair actions for a given aircraft into three bins or buckets. Repairs within a given bin are performed simultaneously, but the bins are repaired serially. Thus, all repairs in bin one are completed before beginning bin two repairs. The repair time for each bin is the longest of the repair times contained in the bin.[26] The MXP model also used three bins. The first bin contained 65 percent of the total number of repair actions, the second bin contained 25 percent, and the third bin contained 10 percent. This is very similar to the probabilities used in the MCR model—60, 30, and 10 percent, respectively.[27]

MXP Model Validation

As previously stated, the least Mx priority system most closely matched the recovery maintenance practices in place at both Dover AFB and Travis AFB. Therefore, the study team deemed the least Mx model the best representation of the current, real-world process and considered this model the *as-is* model. The study team used the HSLDR rate in order to validate the MXP simulation with the real-world

Arrivals (AC)	0	1	2	3	4	5	6	7	8
Sunday	0.231	0.461	0.2	0.093	0.015	-	-	-	-
Monday	0.092	0.139	0.292	0.215	0.108	0.092	0.047	-	0.015
Tuesday	0.015	0.047	0.2	0.261	0.185	0.154	0.107	0.031	-
Wednesday	0.015	0.077	0.093	0.307	0.308	0.138	0.062	-	-
Thursday	-	0.062	0.107	0.216	0.338	0.185	0.092	-	-
Friday	0.077	0.077	0.138	0.293	0.184	0.185	0.031	0.015	-
Saturday	0.169	0.416	0.246	0.061	0.062	0.046	-	-	-

Table 3. Probability of Number of Aircraft Arrivals by Day of the Week

Crew Size (CS)	1	2	3	4	5	6	9
P(CS)	0.323	0.519	0.123	0.022	0.003	0.001	0.009

Table 4. Crew Size Probability

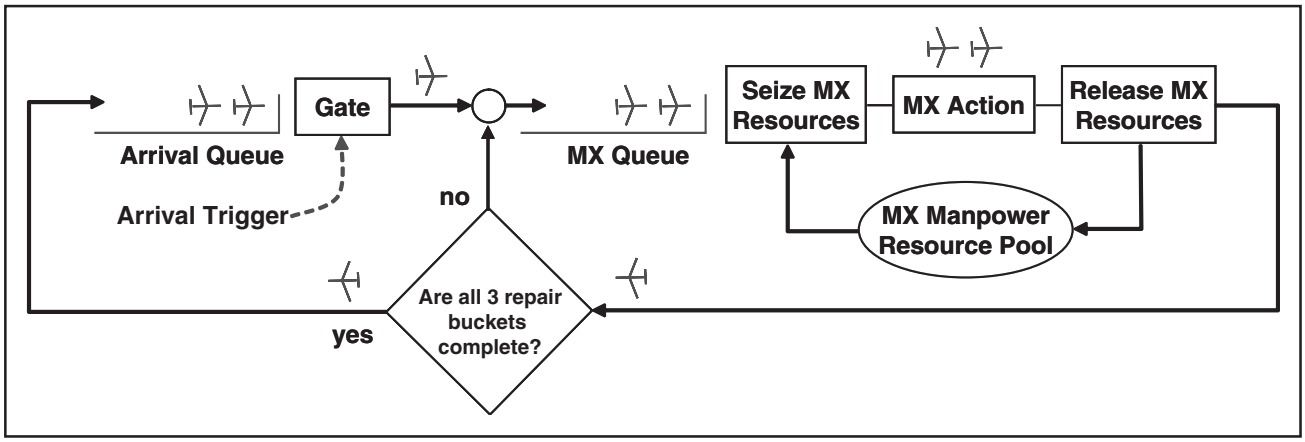

Figure 4. Maintenance Process as Modeled in the C-5 MXP Simulation

Aligning Maintenance Metrics: Improving C-5 TNMCM

An ideal policy is one that would produce a high LDR rate, a low TNMCM rate, and a low Mx backlog.

maintenance processes. After calibrating the MXP, the least Mx model achieved an HSLDR rate of 0.821 with a 95 percent confidence interval that included the real-world HSLDR rate of 0.833 for the timeframe of the data. It is important to note that the model's intended use was not as a predictive model (given C-5 break rates, how many maintenance resources are required to satisfy a given AA rate?), but only to make a relative comparison between the four given prioritization policies. The model was not designed to determine HSLDR/TNMCM/Mx backlog or to determine maintenance manning levels.

MXP Results and Conclusions

Table 5 summarizes the MXP simulation results for the four policies examined with respect to three metrics: HSLDR, estimated TNMCM (Est TNMCM), and Sum of Mx in the queue (Mx backlog). Mx backlog covers the middle ground between the other two metrics—the prioritization policy determines which aircraft the maintenance group returns to mission capable status soonest while the remaining aircraft accrue TNMCM time. Mx backlog is a measure of the ability of the maintenance system to generate all possessed aircraft if called upon to do so. An ideal policy is one that would produce a high LDR rate, a low TNMCM rate, and a low Mx backlog. Table 5 summarizes the results for each policy with regard to these three metrics.

- Least Mx. The least Mx model was the baseline for comparison to the other Mx prioritization policies. It most closely resembled the *as-is* process of recovery maintenance. The HSLDR achieved in the model was representative of the real-world HSLDR rate and was used to validate the model. Likewise, the Est TNMCM rate achieved matched the real-world value for the timeframe of the data. Mx backlog for the least Mx model was the largest for the four policies considered. The Mx backlog measured the ability to improve the steady-state TNMCM rate. The higher the backlog, the harder it was for the Mx system to improve from their steady state TNMCM. Higher backlog means longer aircraft generation time.
- Most Mx. The most Mx prioritization policy had the same LDR (statistically speaking, within a 95 percent confidence interval) as the least Mx policy. Both the Est TNMCM and Mx backlog improved over the least Mx policy. This is intuitive because the most Mx policy actively applies resources to the biggest maintenance jobs first. However, the variability from day to day increased significantly with this policy. This means that the predictability and stability for scheduling purposes suffered greatly.
- FIFO. The FIFO policy had a reduced LDR when compared to the least Mx policy. However, the Est TNMCM improved, and was statistically the same as the Est TNMCM for the most Mx policy (within 95 percent confidence intervals). The Mx backlog was lower than the least Mx policy as well.

- LIFO. The LIFO policy appeared to be the least attractive with regard to the key metrics. As compared to the least Mx policy, it had a reduced LDR and increased Est TNMCM. It also had a reduced Mx backlog when compared to the least Mx policy but was the second worst of all the policies examined.

These results reveal several things about the prioritization policies and their impact to the LDR and TNMCM rates. First, LDR and TNMCM react differently depending on maintenance policy. The current policy in place (least Mx) achieves a high LDR but has a mediocre estimated TNMCM when compared to the other policies, and the worst Mx backlog, which indicates that it is very difficult to improve the TNMCM rate. It is possible to improve the TNMCM rate by changing the prioritization policy. However, the improved TNMCM would come at the cost of predictability and stability in day-to-day operations (as with most Mx policy) and LDR, as is the case with the FIFO policy. The results of the simulation added support to the original hypothesis that HSLDR and TNMCM are not aligned metrics, but did not completely confirm it. While the current system can not be modeled perfectly, the simulation results did suggest that current maintenance policies do not ensure TNMCM improvement, but do improve LDR. It is safe to conclude that TNMCM and LDR are not necessarily aligned, complementary metrics.

Several personnel interviewed during the study team's site visits suggested that awareness exists of the just-described disconnect between enterprise goals (aircraft availability) and operating objectives. "There is a huge disconnect between AMC's focus on the availability of tails (airplanes) and our focus on on-time departure reliability."[28]

Consequently, while process owners are diligently focused on supporting the strategic performance objectives of delivering cargo and passengers, they are unable to simultaneously align their performance with the enterprise goal of increased aircraft availability.[29]

While process owners are diligently focused on supporting the strategic performance objectives of delivering cargo and passengers, they are unable to simultaneously align their performance with the enterprise goal of increased aircraft availability.

Maintenance Metrics at Delta Airlines

As a means of comparing business practices, the study team elected to compare Air Force maintenance metrics with those of a leading commercial organization, Delta Airlines. The team interviewed representatives from Delta Airlines' reliability program office. The study team was told the focus of Delta's reliability program is driven by what is termed as Delays and Cancellations (D&C).[30] These are unscheduled events that have an operational impact and require a mechanical dispatch. For each

Policy	HSLDR	Est TNMCM	Mx Backlog
Least Mx	0.821	0.322	45K
Most Mx	0.816	0.305	23K
FIFO	0.764	0.307	20K
LIFO	0.735	0.393	30K

Table 5. Summary of MXP Results for Study Metrics

Aligning Maintenance Metrics: Improving C-5 TNMCM

Conventional wisdom argues that increased strategic readiness facilitates operational effectiveness—increased AA and decreased TNMCM should lead to increased HSLDR. However, there is a weak correlation between HSLDR and both AA and TNMCM. These metrics are not aligned.

delay or cancellation, there is a direct, net consequence to Delta's revenue, so there is a high priority placed on diagnosing the cause.

Delta personnel identified nine main aircraft maintenance metrics used by Delta. These metrics are summarized in Table 6.[31] Note that technical dispatch reliability (TDR) includes all maintenance related to primary delays and cancellations, whereas mechanical dispatch reliability (MDR) includes only those primary events for which the reliability program is responsible. Repairs due to damage, *cannot duplicate* actions, maintenance carryovers, and maintenance errors (such as over-servicing) are not included in MDR. Dispatches are the term used for all of Delta's revenue flights.[32] Although there is not an explicit hierarchy, the first two metrics, TDR and MDR, are directly linked to the daily revenue-producing flights on Delta's schedule. These metrics track the volume of, and reasons behind, delays and cancellations for a revenue flight.

Maintenance carryovers are Delta Airlines' equivalent to delayed discrepancies in the Air Force. Maintenance carryovers are repairs that may be delayed (or carried over) to a more opportune time. Unscheduled aircraft out of service (UAOOS) measures the number of aircraft out of service due to an unscheduled event (such as a broken component). Delta measures UAOOS by counting the number of aircraft in this category three times per day (0900 hours, 1200 hours, and 1800 hours), and averaging that count over specified intervals.[33] Prioritization of repair is often given to aircraft that can be returned to service quickly, but the level of impact to fleet operations may be the driving factor.[34] As an example, a broken B-777 has a much bigger impact than a broken MD-88; the MD-88 fleet has many spares, while the B-777 does not.[35] The UAOOS metric is analogous to the Air Force TNMCM rate, though it is only focused on the unscheduled aircraft and is counted in whole aircraft rather than hours. Delta's primary metrics (those driven by delays and cancellations) are not measured to an objective standard (*met* or *not met*), instead, they *alert* when they exceed a control limit for 2 consecutive months.[36] Additionally, Delta personnel interviewed suggested that the metrics are driving desired behavior; this is supported by measured performance, as TDR averaged 97 percent fleet-wide at the time of the original study's publication.[37]

Delta has a very clear enterprise-level value measure—profit. This clear value measure lends itself well to metric definition at the operational level, which is why Delta focuses on the D&Cs. The D&Cs have a direct net effect on the revenue producing flights, which in turn has a direct impact on profit.

Value Metrics in the Mobility Air Forces

The MAF on the other hand, seems to have two competing enterprise-level value metrics.

- Strategic Readiness. AA and TNMCM rates measure the ability of the fleet to be fully mobilized at any given time

- Operational Effectiveness. HSLDR rates measure the ability of the fleet to meet the daily mission requirements.

Conventional wisdom argues that increased strategic readiness facilitates operational effectiveness—increased AA and decreased TNMCM should lead to increased HSLDR. However, as previously shown, there is a weak correlation between HSLDR and both AA and TNMCM. Again, these metrics are not aligned.

Conclusions

This article discussed the focus on different metrics to include HSLDR, TNMCM, and AA at varying levels of the Air Force maintenance enterprise. It also demonstrated that HSLDR is aligned with neither AA nor TNMCM, as there is only a weak correlation between them. Maintainers at the wing level work to support

Metric	Formula
Mechanical Dispatch Reliability (MDR)	$100 - \left(\left(\frac{\text{Delays + Cancellations}}{\text{Revenue Departures}}\right) \times 100\right)$
Technical Dispatch Reliability (TDR)	$100 - \left(\left(\frac{\text{Technical Issues}}{\text{Revenue Departures}}\right) \times 100\right)$ Where technical issues include dispatches for mechanical, process, policy, and paperwork issues associated with delays and cancellations.
Unscheduled Aircraft Out of Service (UAOOS) Count	Number of Unscheduled Aircraft Out of Service
In-Flight Shutdown Rate (IFSDR)	$\frac{(\text{Total Inflight Shutdowns x 1,000})}{\text{Total Engine Hours}}$
Maintenance Carryovers (MCO) Count	Number of Maintenance Carryovers
MEL Count	Number of Restricted Items
Unscheduled Removal Rate (Used for the Engines and APUs)	$\frac{(\text{Total Unscheduled Removals x 1,000})}{\text{Total Hours}}$
Pilot Reports (PIREPS)	$\left(\frac{\text{Pilot Reports x 1,000}}{\text{Total Flying Hours}}\right)$
Flight Exception Rate	Number of Diversions, Air Turn Backs and Rejected Takeoffs for Mechanical Reasons

Table 6. Delta Airlines Maintenance Metrics

Aligning Maintenance Metrics: Improving C-5 TNMCM

If the Air Force's primary goal is to improve the C-5 fleet TNMCM rate, then priorities of the maintainers in the field must change. As the MXG leadership focuses on HSLDR performance, not TNMCM, the MXP simulation indicated that improving the TNMCM rate would require an increase in resources. Therefore, in order to improve the TNMCM rate without increased resources, the maintainers in the field must make TNMCM a priority.

operational effectiveness; however, higher levels of Air Force supervision appear more focused on improving strategic readiness. This disconnect in priorities was determined to be a root cause of the C-5 TNMCM rate being below Air Force standards. This article does not advocate one metric over another. That choice is left for Air Force leadership to make. This article illustrates that, in this case, the primary metrics at varying levels of aircraft maintenance are not aligned and not complementary to one another.

If the Air Force's primary goal is to improve the C-5 fleet TNMCM rate, then priorities of the maintainers in the field must change. As the MXG leadership focuses on HSLDR performance, not TNMCM, the MXP simulation indicated that improving the TNMCM rate would require an increase in resources. Therefore, in order to improve the TNMCM rate without increased resources, the maintainers in the field must make TNMCM a priority. While it is impossible to model the current system perfectly, the results suggest that current maintenance policies do not ensure TNMCM improvement, but do improve HSLDR, which is the stated priority of the MXG leadership. Therefore, the study team recommended that MAJCOM A4 leadership and MXG leadership decide on a set of metrics that are better aligned toward the same goal.

This realignment of metrics must start at the highest levels of the MAF. The MAF should choose its value measure and create a set of metrics aligned with that measure. For example, if the MAF directs that operational effectiveness is its primary value, then metrics such as Tons of Cargo Moved or Million Ton Miles Moved over a given time period could be used as the value metric. Then it must be determined whether or not metrics at lower levels are aligned with the value metric. Once that is determined, all levels of maintenance leadership will have the same overarching priorities. Dr Hammer describes the entire view as *pulling it together* and lists three things to consider:

- Deciding what to measure is a science
- Deciding how to measure is an art
- Using measures is a process

Recommendations

- If improving C-5 TNMCM rates is the goal, all levels of maintenance leadership must make improving TNMCM rates a priority.
- AMC should determine its priorities between operational effectiveness and strategic readiness, and determine metrics aligned with these priorities.
- Conduct a study to determine whether or not increased AA is correlated with increased operational effectiveness in million ton miles or another pertinent metric. The answer to this question will help determine the applicability of AA towards measuring operational effectiveness.

- AMC/A4 develop simpler, more concrete maintenance metrics that are easily countable and give an indication that operational effectiveness and or strategic readiness is going to be affected.

As previously mentioned, the metrics analysis, modeling, and simulation described in this article was developed as part of the larger *C-5 TNMCM Study II*. This is the second in a series of articles related to that study. The entire study can be found at the Defense Technical Information Center (DTIC) Private Scientific and Technical Information Network (STINE T) Web site at https://dtic-stinet.dtic.mil/.

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Establishing C-5 TNMCM Standards

Introduction

This article details the process for calculating and establishing Air Force aircraft total not mission capable maintenance (TNMCM) standards. It is impossible to discuss the TNMCM rates and standards without including discussions of the mission capable (MC) and the total not mission capable supply (TNMCS) rates and standards. These three rates are dependent upon one another. Because the rates are percentages of total unit-possessed time, one rate cannot increase or decrease without impacting the other two. The Air Force standards applied to these metrics are interrelated as well. As discussed in this article, the TNMCM and TNMCS standards depend on the MC standard. Thus, the formulation of the MC standard is the foundation for the TNMCS and TNMCM standards.

The 2003 CORONA directed that Air Force-wide standards for MC, TNMCM, and TNMCS be established. While directed toward TNMCM, the research detailed in this article also revealed that the MC standard is the foundation for calculating the other two metric standards. As the process exists currently, the Air Force MC standards are based on requirements which are determined in one of three ways:

- The flying hour or flying schedule requirement
- Contract logistics support (CLS) contract
- Another requirement based on major command (MAJCOM) input determined by the designed operational capability (DOC) statement, readiness study, or any operational requirement the MAJCOM may use

In the case of the Air Force's C-5 Galaxy, Air Mobility Command (AMC) provides the active duty fleet MC standard to the Air Staff based on the *Mobility Requirements Study* (MRS). However, the standard is not actually calculated in the MRS, it is an assumption used in the MRS.

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Air Force Instruction 21-101, Aircraft Equipment and Maintenance Management, defines the MC, TNMCS, and TNMCM metrics and their uses.

This is not the case for the separate Air Force Reserve Command (AFRC) and Air National Guard (ANG) fleet C-5 MC standards. Those two values are calculated at the Air Staff level. The AFRC MC standard is calculated from utilization rate, attrition, turn pattern, annual fly days, spares, aircraft held down for scheduled maintenance, and primary aerospace vehicles authorized. The ANG MC standard equation uses variables portraying daily operations and maintenance (O&M) flying hours, aircraft taskings per flying day over and above O&M flying, average number of aircraft required for standard flying operations each day, required daily spares, and the forecasted number of unit possessed aircraft over the year.

Background

This article is the third in a three-part series based on Air Force Logistics Management Agency (AFLMA) project number LM200625500, the *C-5 TNMCM Study II*. At the request of the Air Force Materiel Command Director of Logistics (AFMC/A4), an AFLMA study team conducted an analysis in 2006-2007 of TNMCM performance with the C-5 aircraft as the focus. The *C-5 TNMCM Study II* included five objectives. One of those objectives was to analyze the process for calculating and establishing aircraft TNMCM standards. This article details the analysis conducted in support of that particular study objective.

Maintenance Metric Definitions

Air Force Instruction (AFI) 21-101, *Aircraft Equipment and Maintenance Management,* defines the MC, TNMCS, and TNMCM metrics and their uses. For additional insight on the use of these metrics see *Metrics Handbook for Maintenance Leaders*.

Mission Capable (MC) Rate

Though a lagging indicator, the MC rate is perhaps the best known yardstick for measuring a unit's performance. It is the percentage of possessed hours for aircraft that are fully mission capable (FMC) or partially mission capable (PMC) for specific measurement periods (such as monthly or annually).[1]

$$\text{MC (\%)} = \frac{\text{FMC Hours + PMC Hours}}{\text{Possessed Hours}} \times 100\%$$

Total Not Mission Capable Maintenance (TNMCM) Rate

Though a lagging indicator, the TNMCM rate is perhaps the most common and useful metric for determining if maintenance is being performed quickly and accurately. It is the average percentage of possessed aircraft (calculated monthly or annually) that are unable to meet primary assigned missions for maintenance reasons (excluding aircraft in *B-Type* possession identifier code status). Any aircraft that is unable to meet any of its wartime missions is considered not mission capable. The

TNMCM is the amount of time aircraft are in NMCM plus not mission capable both (NMCB) status.[2]

$$\text{TNMCM (\%)} = \frac{\text{NMCM Hrs + NMCB Hrs}}{\text{Possessed Hours}} \times 100\%$$

Total Not Mission Capable Supply (TNMCS) Rate

Though this lagging metric may seem a logistics readiness squadron responsibility because it is principally driven by availability of spare parts, it is often directly indicative of maintenance practices. For instance, maintenance can keep the rate lower by consolidating feasible cannibalization actions to as few aircraft as practical. This monthly (annual) metric is the average percentage of possessed aircraft that are unable to meet primary missions for supply reasons. The TNMCS rate is the time aircraft are in not mission capable supply (NMCS) plus not mission capable both maintenance and supply (NMCB) status. TNMCS is based on the number of airframes out for mission capable (MICAP) parts that prevent the airframes from performing their mission (NMCS is not the number of parts that are MICAP).[3]

$$\text{TNMCS (\%)} = \frac{\text{NMCS Hrs + NMCB Hrs}}{\text{Possessed Hours}} \times 100\%$$

Fiscal Year (FY) 2007 C-5 Fleet Standards and Standards Calculations

As previously mentioned, during a 2003 CORONA, the Air Force Chief of Staff (CSAF) directed the establishment of Air Force-wide standards for the MC, TNMCS, and TNMCM metrics. Headquarters (HQ) Air Force Instalations and Logistics (now AF/A4) was named the office of primary responsibility (OPR). Their charter was to develop Air Force standards rooted in operational requirements and resources dedicated to each weapon system or mission design series (MDS). They subsequently developed calculation methodologies for calculating MC, TNMCS, and TNMCM standards. However, as of the time of the original study research, the study team found no official publication documenting the methodology for calculating these maintenance metric standards. Consequently, OPRs at the HQ Air Force and MAJCOM levels provided the study team with the definitions for the calculation methodologies that produced the C-5 fleet maintenance standards used in FY 2007. Table 1 summarizes the 2007 C-5 standard percentage rates for the MC, TNMCS and TNMCM metrics. An explanation of each method for deriving the standards follows.

MC Standard

The MC standard provides the foundation for calculating the other maintenance metric standards. According to HQ Air Force, Directorate of Maintenance,

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		Active Duty	ARC	*AFRC*	*ANG*
MC	**Standard**	75	50	*50*	*47*
	Method	*MAJCOM Input*	*Equation 3*	*Equation 1*	*Equation 2*
TNMCS	**Standard**	8	8		
	Method	*Equation 4*	*Equation 4*		
TNMCM	**Standard**	24	50		
	Method	*Equation 6*	*Equation 6*		

Table 1. FY 2007 C-5 Maintenance Standards and Calculation Methodologies[4]

Weapons Systems Division, Sustainment Branch (AF/A4MY) personnel, the MC standards are based on requirements. The MC standard represents the percentage of MC aircraft required at the beginning of each flying day. That requirement is determined by one of the following three ways:[5]

- The flying hour or flying schedule requirement, calculated using Equation 1, 2, or 3.
- Contract logistics support (CLS) contract.
- Some other requirement based on MAJCOM input. That input can be a DOC statement, readiness study, or any operational requirement the MAJCOM may use.

The Air Reserve Component (ARC), a composite of both ANG and AFRC, MC standard is based on the number of aircraft committed to the flying schedule. However, the ANG flying commitment is based on O&M flying hours, transportation working capital fund (TWCF) hours, and the number of operations alert committed aircraft per flying day. Also included is the daily spares requirement. This commitment in aircraft is divided by the forecasted possessed aircraft to determine the MC requirement.[6]

Each year, AF/A4MY personnel request input from AMC for the MC standard. AMC determines the MC rate necessary to meet their airlift requirement and then gives their desired MC rate to Air Staff. Air Staff then uses this rate as the MC standard. This process is currently used to determine the active duty MC standards for the C-17, C-5, C130, KC-10, and KC-135 airframes.[7] These MC standards are based solely on AMC's input. AF/A4MY personnel do not calculate the MC standard for any of the above listed active duty fleets.

The three MC standard requirement algorithms are detailed in Equations 1, 2, and 3. Equation 1 is typically used with active duty aircraft fleets.

Where:

$$MC_{Std} = \left[\frac{12 \times UTE}{(1 - Attrition) \times (Turn\ Pattern) \times (Fly\ Days)}\right] + \left[\frac{Spares + MC_{SchdMX}}{PAA}\right]$$

Equation 1. MC Standard[8]

MC_{std} is MC Standard.

UTE is the sortie utilization rate, which is the number of sorties required to fly each month by authorized aircraft. 12 x *UTE* yields the annual sorties required to meet the flying-hour program (FHP).

Attrition is the annual attrition rate of sorties lost due to operations, maintenance, and other considerations such as weather. Dividing by (1-*Attrition*) yields the sorties required to be scheduled to account for attrition.

Turn pattern, or turn rate, is the total number of sorties scheduled divided by the number of *first go* sorties. For example: a unit schedules 100 sorties during the week and 60 of them occur on the *first go* of the day. The turn rate would be 100/60 = 1.67. Dividing by *turn pattern* yields the number of front-line flyers. Dividing by the number of *fly days* yields the number of front-line flyers per day.

Fly Days = 232. This figure assumes 244 *working days* minus 12 g*oal days*.

Spares, or front line spares, is the number of scheduled spare aircraft for the *first go*.

MC_{SchdMX} is the average number of aircraft per squadron held down on each flying day for scheduled maintenance including delayed discrepancies, health of the fleet management, washes, and so forth.

Spares + MC_{SchdMX} is expressed as a percentage of squadron possessed aircraft authorized (PAA).

PAA is the number of aircraft authorized for a unit to perform its operational missions.[9]

Equation 2 is the algorithm used by the ANG.

Where:

$$MC_{ANG} = \left\lceil \frac{\left\lceil AC_{O\&M} + AC_{TWCF/BE/AE} + AC_{Ops} + Spares \right\rceil}{AC_{Forecast}} \right\rceil$$

Equation 2. MC Standard for ANG[10]

$AC_{O\&M}$ is the average number of committed aircraft based on the O&M requirements per flying day.

$AC_{TWCF/BE/AE}$ is the number of aircraft required for taskings per flying day that the ANG supports above its O&M flying (such as TWCF, aeromedical evacuation (AE), business effort [BE]).

AC_{Ops} is the average number of aircraft required for standard flying operations per flying day.

Spares is the same as in Equation 1, but is reported as the number of aircraft per flying day.

$AC_{Forecast}$ is the number of aircraft that are expected to be unit possessed over the year based on depot maintenance schedules and other considerations.

$\lceil x \rceil$ shown in the numerator of Equation 2 denotes the smallest integer greater

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than or equal to x. This function rounds any decimal value up to the next whole number. The ceiling function is used in order to speak in terms of whole aircraft.

Equation 3 is utilized to calculate the MC standard for the composite ARC portion of an aircraft fleet.

The MC standard for the AFRC (MC_{AFRC}) fleet is calculated using the standard

$$MC_{ARC} = \frac{(MC_{AFRC} \times PAA_{AFRC}) + (MC_{ANG} \times PAA_{ANG})}{PAA_{AFRC} + PAA_{ANG}}$$

Equation 3. MC Standard for ARC Fleet[11]

MC equation given in Equation 1. For simplicity, the result of this formula is rounded to the nearest tenth.

TNMCS Standard

Active duty and ARC fleets use the same methodology for TNMCS once the MC standard is established. This calculation is shown in Equation 4. Note that separate TNMCS standards for AFRC and ANG are not calculated.

The aircraft availability target (AAT) ties the TNMCS standard to the funding

$$TNMCS_{Std} = 1 - AAT$$

Equation 4. TNMCS Standard[12]

and requirements for spare parts that are calculated in the Requirements Management System.[13] It assumes the supply pipeline and spare safety levels are fully funded. The *AAT* for the C-5 has been at 92 since the beginning of the maintenance standard development. This yields a TNMCS standard of 8 which is applied to both ARC components.

Equation 5 defines the aircraft availability target calculation.

Required MC is determined the same way that the Air Force active duty MC standard is determined.[15]

$$AAT = Required\ MC + NMCM_{3\ year\ historical}$$

Equation 5. AAT Calculation[14]

$NMCM_{3\ year\ historical}$ is the 3-year historical average of the NMCM rate for the particular MDS under consideration.

It is important to note that the maintenance metrics standards established for FY07 (Table 1) used the FY05 calculated AATs. This is because the C-5 parts on the shelf in FY07 were based on the FY05 AATs.[16] As just mentioned, the FY05 AAT for the C-5 fleet was 0.92. The Logistics Management Institute (LMI) updated the AAT-setting methodology in 2006 to include computations for *Required MC* and NMCM rates for both day-to-day operations and predeployment.[17]

TNMCM Standard

Active duty and ARC fleets use the same methodology for TNMCM once the respective MC standard is established. This calculation is shown in Equation 6. Note that separate TNMCM standards for AFRC and ANG are not calculated.

$NMCB_{3\ yr\ historical}$ is the average NMCB rate over the previous 3 years. The data used for the FY07 calculation came from the Reliability and Maintainability Information System (REMIS); the average NMCB for FY04, FY05, and FY06 equaled 0.07.[19]

$$TNMCM_{Std} = 1 - (MC_{Std} + TNMCS_{Std}) + NMCB_{3\ yr\ historical}$$

Equation 6. TNMCM Standard[18]

Standards Calculation Examples

This section applies the above formulas to the real-world data that produced the metric standards in Table 1.

FY07 Active Duty C-5 Fleet

MC Standard (MAJCOM Input):

AMC stated that the MC standard is 0.75 (75 percent) based on an operational requirement used in the Mobility Requirements Study (MRS) 2005 (MRS-05).

TNMCS Standard (Equation 4):

$$TNMCS_{Std} = 1 - AAT = 1 - 0.92 = 0.08$$

TNMCM Standard (Equation 6):

$$\begin{aligned} TNMCM_{Std} &= 1 - (MC_{Std} + TNMCS_{Std}) + NMCB_{3\ yr\ historical} \\ &= 1 - (0.75 + 0.08) + 0.07 \\ &= 0.24 \end{aligned}$$

FY07 ARC C-5 Fleet

The data required to calculate the ARC standards for FY07 is given in Table 2. AFRC and ANG provided the data in response to the FY07 Air Force Standards Data Call.

The PAA numbers the commands provided were 32 for the AFRC and 16 for the ANG. These values reflected the PAA before the PAA was adjusted to accommodate units recently gaining C-5s. To compute the AFRC MC standard, AF/A4MY used the PAA based on AFRC input, which was 32. However, for the weights in determining the composite ARC MC standard, AF/A4MY used the PAAs for FY07, which included the additions for the gaining units. These values are 40 for AFRC and 29 for ANG.

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AFRC MC Standard (Equation 1):

$$MC_{AFRC} = \left[\frac{12 \times UTE}{(1 - Attrition) \times (Turn\ Pattern) \times (Fly\ Days)}\right] + \left[\frac{Spares + MC_{SchdMX}}{PAA}\right]$$

$$MC_{AFRC} = \left[\frac{12 \times 8.5}{(1 - 0.23) \times (1.3) \times (232)}\right] + \left[\frac{2 + 0}{32}\right] = \left[\frac{102}{232.232}\right] + \left[\frac{2}{32}\right] = 0.502$$

ANG MC Standard (Equation 2):

$$MC_{ANG} = \left[\frac{\left[AC_{O\&M} + AC_{TWCF/BE/AE} + AC_{Ops} + Spares\right]}{AC_{Forecast}}\right]$$

$$= \left[\frac{\left[3.84 + 1.19 + 0.45 + 1.3\right]}{15}\right]$$

$$= \left[\frac{\left[6.78\right]}{15}\right] = \left[\frac{7}{15}\right] = 0.47$$

ARC MC Standard (Equation 3):

$$MC_{ARC} = \frac{(MC_{AFRC} \times PAA_{AFRC}) + (MC_{ANG} \times PAA_{ANG})}{PAA_{AFRC} + PAA_{ANG}}$$

$$= \frac{(0.50 \times 40) + (0.47 \times 27)}{67} = 0.488 \approx 0.50$$

TNMCS Standard (Equation 4):

$$TNMCS_{Std} = 1 - AAT = 1 - 0.92 = 0.08$$

TNMCM Standard (Equation 6):

$$TNMCM_{Std} = 1 - (MC_{Std} + TNMCS_{Std}) + NMCB_{3\ yr\ historical}$$

$$= 1 - (0.50 + 0.08) + 0.08$$

$$= 0.50$$

Of note is the fact that the 3-year average NMCB was actually 0.166 (based on Multi-Echelon Resource and Logistics Information Network [MERLIN] data). AF/A4MY capped the NMCB at 0.08 because the historical NMCB cannot theoretically exceed the TNMCS. Recall that TNMCS is the sum of NMCS and NMCB; therefore, NMCB *should be* less than or equal to TNMCS.[21] The TNMCS standard is

	PAA Command Input	PAA (FY07 Actual)	UTE	Attrition	Turn Pattern	Fly Days	Spares	MC for Sched Mx
AFRC	32	40	8.5	0.23	1.3	232	2	0
	PAA Command Input	PAA (FY07 Actual)	O&M AC/day	TWCF,BE, AE AC/day	Spares/ day	Ops AC/day	Possessed AC Forecast	
ANG	16	27	3.84	1.19	1.3	0.45	15	

Table 2. Data for AFRC and ANG MC Standard Calculations[20]

established as a resourced goal and the Air Force is trying to achieve a balance in the maintenance standards.[22]

AMC Determination of the C-5 MC Operational Requirement

According to AF/A4MY and AMC/A4MXA, AMC provides Air Staff with the value for the MC standard for the active duty fleet. This standard has been 75 percent since 2003, the year that Air Force-wide standards were implemented.[23] AMC/A4MXA stated that the value of 75 percent was based on the MRS.[24] According to the AMC/A9 office, every major mobility study including the MRS (1992), the *MRS Bottom-Up Review Update* (1995), MRS-05 (2000), and the *Mobility Capabilities Study* (2005), has used 75 percent as the C-5 MC rate standard to determine the capability of the C-5 fleet to support the mobility forces.[25]

Examination of the MRS-05 revealed the MRS-05 did not calculate an MC standard—the MRS-05 assumed an MC rate of 76 percent for a fleet in which all C-5s have had the Reliability Enhancement and Re-Engining Program (RERP) modifications. The MRS-05 explains that the use of 76 percent MC rate is because of expected RERP improvements. The study also assumes a 65 percent MC rate for aircraft that have not received the RERP improvements.[26] The director of the AMC office of Analysis, Assessments, and Lessons Learned (AMC/A9) concurred that the C-5 MC standard is not based on any formal calculation or analysis, and stated that the original estimate (circa 1990) of a 75 percent MC rate was deemed "a prudent objective" for planning purposes.[27] AMC/A9 stated that the 75 percent MC rate assumes a fully mobilized total force to support C-5 maintenance operations.[28]

In summary, the FY07 MC, TNMCS, and TNMCM standards for the C-5 active duty fleet are based on the assumption that the C-5 fleet can achieve a 75 percent MC rate with the entire fleet receiving RERP upgrades or a fully mobilized total force to support maintenance operations.

The FY07 MC, TNMCS, and TNMCM standards for the C-5 active duty fleet are based on the assumption that the C-5 fleet can achieve a 75 percent MC rate with the entire fleet receiving RERP upgrades or a fully mobilized total force to support maintenance operations.

While the functional mission differences between fighter and mobility aircraft may justify distinct calculation methodologies, inconsistencies within a given airframe (for example, the C-5) are less easily supported. Consistency, in fact, is identified by AFI 21-101 as one of four important characteristics of a metric.

Implications of the Methodology

There are numerous implications of this complex, seemingly disjointed standards methodology that are problematic for Air Force members at the strategic, operational, and tactical levels. First, Equation 1, in its present state, is more appropriate for fighter aircraft than mobility aircraft.[29] For example, the *Turn Pattern* and MC_{SchdMX} variables are reflective of fighter aircraft flying schedules. Mobility aircraft are less often *turned* on the same flying day, and mobility aircraft units, having a relatively small number of PAA, often have less opportunity to hold aircraft down for fleet health purposes. Consequently, this is a contributing factor to AF/A4MY's rationale of using AMC's input to determine active duty standards. The study team concluded that if Equation 1 is not appropriate for heavy aircraft, then it should not be used as a foundation for the MC standard. The variables used to measure performance need to accurately reflect the relevant process.

An additional issue is a lack of consistency across the total force components. The active duty component uses AMC input to determine the MC standard, but the ARC uses calculation methodology. Moreover, in addition to the planning objective used to determine the active duty maintenance standards and the calculations used to determine the ARC standards, the total force components, including the ANG, have maintenance metric goals. These goals are separate from the Air Force standards and are calculated differently. Within the ANG, units report their performance with regard to the ANG goals, and not necessarily the ARC metric standards. While the functional mission differences between fighter and mobility aircraft may justify distinct calculation methodologies, inconsistencies within a given airframe (for example, the C-5) are less easily supported. Consistency, in fact, is identified by AFI 21-101 as one of four important characteristics of a metric. These four characteristics are:

- Accurate and useful for decisionmaking
- Consistent and clearly linked to goals or standards
- Clearly understood and communicated
- Based on a measurable, well-defined process[30]

The fourth characteristic mentioned above highlights another concern given the current methodology for calculating the C-5 standards. Fundamentally, the process is not rigidly followed as part of formal policy; rather, the practice of establishing standards involves numerous deviations, discussed at length earlier in this article (active duty MC input, AAT from FY05, ANG goals). Simply stated, there was no complete, published, defined process. In April 2003, the United States Government Accountability Office (GAO) discussed these same issues in a report addressing aircraft availability goals across the Department of Defense (DoD).[31] The GAO found that all branches of military Service fail to clearly define the standards computation process for aircraft maintenance metrics.

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The following selected comments were taken from the GAO report's executive summary:

> Despite their importance, DoD does not have a clear and defined process for setting aircraft availability goals. The goal-setting process is largely undefined and undocumented, and there is widespread uncertainty among the military Services over how the goals were established, who is responsible for setting them, and the continuing adequacy of MC and FMC goals as measures of aircraft availability. DoD guidance does not define the availability goals that the Services must establish or require any objective methodology for setting them. Nor does it require the Services to identify one office as the coordinating agent for goal setting or to document the basis for the goals chosen.[32]

Speaking in terms of consequence, the GAO suggested that the "lack of documentation in setting the goals ultimately obscures basic perceptions of readiness and operational effectiveness."[33] Additionally, the report documented several findings specifically relevant to establishing standards for the Air Force. These findings included:

- Air Force officials told [the GAO] that they generally try to keep the goals high because it is difficult to stop the goals from dropping further once they begin to be lowered.[34]
- Air Combat Command could find no historical record of the process used to establish most of the goals.[35]
- AMC compared the goals with the actual rates for the previous 2 years. Depending upon actual performance, the goal could then be changed, sometimes on the basis of subjective judgments.[36]

It is vitally important to examine the effectiveness and validity of metrics and their associated standards. Many hours are spent preparing for and participating in meetings discussing the performance of organizations, all of which is wasted if the metrics or standards are ineffective at measuring organizational performance and driving the desired behavior. Budgets and other requirements are driven in part from metrics. If the metrics being utilized are not valid, the effectiveness of the organization to meet warfighter needs is also difficult to accurately measure.

It is vitally important to examine the effectiveness and validity of metrics and their associated standards. Many hours are spent preparing for and participating in meetings discussing the performance of organizations, all of which is wasted if the metrics or standards are ineffective at measuring organizational performance and driving the desired behavior.

Air Force maintenance metrics are presented with an associated numerical standard or goal[37] and managers are required to account for failure to meet those standards. These failures are reported at unit, command, and Air Force levels, but what if the established standard is inaccurate, unrealistic, or unattainable? Consider Table 3, which identifies historical MC performances for the C-5 at various points in time compared with the assumption used in establishing the C-5 MC standard.

During Operations Desert Shield and Desert Storm in FY91, the MC rate was less than 71 percent. During Operation Iraqi Freedom in FY03, the MC rate was less than 64 percent. This is particularly intriguing because numerous personnel interviewed during the original research suggested MC rates have been or should be usually better during conflicts.[39] Indeed, the highest quarterly MC rate the C-5

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The study team interviewed many subject matter experts while conducting site visits for this research. Some of them indicated the consistent inability to achieve an MC standard of 75 percent led to an attitude of frustration, indifference and apathy towards the standards. AFI 21-101 states that "metrics shall be used at all levels of command to drive improved performance." In the case of the C-5, the existing maintenance standards methodology associated with the MC and TNMCM metrics appear to cause those metrics to fall short of this goal.

	MC Rate	Time Period
AMC C-5 MC Standard	75%	~1990 – Present[38]
Operation Desert Shield/Desert Storm	70.6%	Fiscal Year 1991
Operation Iraqi Freedom	63.4%	Fiscal Year 2003
Highest Quarterly MC Rate Achieved	81.8%	Fiscal Year 1991, Quarter 1

Table 3. C-5 Fleet Historically Achieved MC Rates[38]

total fleet achieved, 81.8 percent, was observed during first quarter of FY91 (during Operation Desert Shield). Considering the data points in Table 3 are rates achieved during wartime scenarios, the feasibility of using 75 percent as the day to day, peacetime C-5 MC standard appears questionable at best.

Still, consistent failures to meet a standard can often be perceived as a shortfall in the performance of the units supporting the C-5, rather than an unrealistic expectation not being met. Again, a tremendous amount of time and effort is put forth explaining why standards are not met. Historical C-5 MC rate performance would suggest that the standard and its associated metric are not driving improvement in performance, which is the fundamental purpose of a performance measure. A metric and its associated standard should drive performance, not simply document it, and the measure should be useful for decisionmaking. Additionally, the *Air Force Smart Operations for the 21st Century Concept of Operations (CONOPS)* identifies good process metrics as having the following attributes:[40]

- Accurate – reliably expresses the phenomenon being measured
- Objective – not subject to dispute
- Comprehensible – readily communicated and understood
- Easy – inexpensive and convenient to compute
- Timely – data sources are available
- Robust – resistant to being gamed and hard to manipulate[41]

As previously stated, the current standards methodology involves differences across the total force. Additionally, the study team interviewed many subject matter experts while conducting site visits for this research. Some of them indicated the consistent inability to achieve an MC standard of 75 percent led to an attitude of frustration, indifference and apathy towards the standards.[42] AFI 21-101 states that "metrics shall be used at all levels of command to drive improved performance."[43] In the case of the C-5, the existing maintenance standards methodology associated with the MC and TNMCM metrics appear to cause those metrics to fall short of this goal.

Alternative Strategies to Performance Measurement

As described in the second article in this series, the AFLMA study team interviewed representatives from the Delta Airlines reliability programs office

as a means of comparing business practices. Delta personnel identified nine main aircraft maintenance metrics. Of note was the fact that Delta's primary metrics (those driven by delays and cancellations) were not measured to an objective standard (met or not met); instead, they alert when they exceed a control limit for 2 consecutive months.[44]

Using control limits, found in control charts, is a commonly used technique for determining if a process is in a state of statistical control. First developed by Shewhart, many influential quality leaders have advocated the proper use of control charts, most notably W. Edwards Deming. Generally speaking, recent data is examined to determine the control limits that apply to future data with the intent being to ascertain whether the process is in a state of control.[45] Charts alone cannot induce process control; stabilization or improvement is the challenge of people in the process.[46] Viable control limits can only be developed for processes in a state of statistical control, and they are best applied to process variables rather than product variables.[47] For example, consider the manufacturing process of a metal component. The product variables might be thickness or diameter, whereas process variables could be temperature or pressure at the point of forging. The benefit of monitoring process variables better allows someone to assign cause to variation. Using the previous example, variance in component diameter indicates a problem but requires further investigation to determine the cause. However, excessive pressure measurements identify the cause behind improper component diameter. Essentially, process variable measurements identify causes that could affect product variables.[48]

Today, many maintenance units are using versions of control charts to monitor performance in terms of the various metrics listed in AFI 21-101.[49] For example, Figure 1 illustrates TNMCM performance (large solid black line), with upper and lower control limits (represented by the solid red lines), at Dover Air Force Base (AFB) during calendar year 2006. Although the effort to use control charts is a step in the right direction, there can be two major problems associated with the use of charts akin to those of Figure 1.

First, Air Force metric measurements such as TNMCM are not process variables; consequently, they do not lend themselves to the immediate, precise root-cause analysis that usually follows from control charts. This is evidenced by the copious explanatory notes pages accompanying products like the CSAF quarterly review slideshow.[51] In fact, the *C-5 TNMCM II* study team's analytical effort identified 184 factors that bear influence on the C-5 TNMCM rate. An additional confounding element is that status of aircraft and the categorization of hours (such as *possessed*) bear direct influence on the outcome of rates such as TNMCM, and this process is not consistent. Study team discussions with maintenance personnel revealed that aircraft status is not an exact science, and status documentation can be vulnerable to manipulation for the sake of improving numbers. For example, this can happen by delaying aircraft status changes by not changing the status to NMCM or NMCS as soon as an aircraft breaks and maintenance is underway or work stoppage occurs due to needed parts.

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Establishing C-5 TNMCM Standards

The categorization of hours is something that is in stark contrast with the host of metrics used by Delta Airlines, which upon examination appeared more tangible, more easily measured, and less easily manipulated.

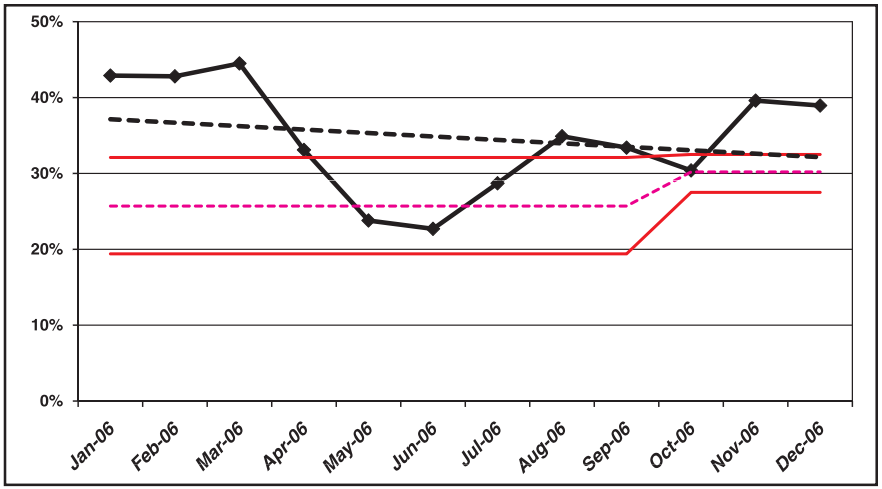

Figure 1. Example of TNMCM Control Chart, Dover AFB 2006[50]

The categorization of hours is something that is in stark contrast with the host of metrics used by Delta Airlines, which upon examination appeared more tangible, more easily measured, and less easily manipulated. Again, a thorough discussion of Delta's maintenance metrics was included in the second article in this series.

Next, upon examination of the control chart in Figure 1, one sees that the centerline mean (small dashed line between the solid red lines) is set at 30.2 for the months in FY07, with the upper and lower control limits set at 32.5 and 27.5, respectively.[52] The study team sought to uncover the specific methodology used to arrive at the centerline mean, as well as the upper and lower control limits. Personnel at Dover stated that the control limits are downward directed from headquarters AMC. The managing office at AMC stated that the control limits were derived from 2 years of historical data for all of AMC, with a range of one standard deviation above and below the mean.[53] There are two issues with this approach. First, the figure is not arrived at through subgroup sampling of at least 20 subgroups, as advocated by statistical analysis literature.[54] Secondly, this centerline mean is known as the *AMC goal* for the TNMCM rate. Interestingly, it is higher (that is, less ambitious) than the active duty TNMCM standard, which was 24 for the FY07 timeframe. The fact that AMC units are using a different figure than the established active duty standard for management purposes is further evidence that fleet standards appear to have limited influence on performance at base levels.

However, as noted in the 2005 AMC Metrics Handbook, because AMC command goals are rooted in wartime operational requirements, there are some standards that are difficult or impossible to achieve during peacetime operations.

> Using the *command average* is one way around this shortcoming. Comparing (your base) to command averages helps to gauge true performance and is invaluable for

> identifying if a problem is local or fleet wide. AMC weapons system managers (WSMs) use command averages for understanding overall performance of their fleets. When discussing performance problems with AMC WSMs, base personnel should have a good understanding of where their base performance numbers are in relation to the command average.[55]

It should be noted that the study team was not advocating the use of the active duty standard as the centerline mean for this control chart. In fact, extreme caution must be taken when using a standard value as opposed to the sampling mean as the centerline for performance. Although the intent might be to control the process mean at a particular value, one runs the risk that the current process is incapable of meeting that standard. For example, if the lower and upper control limits are calculated from the standard, and the current process mean exceeds the standard, subgroup averages might often exceed the upper limit, even though the process is in control. This lessens the ability to determine assignable causes of variation, because the only observation is that the process isn't conforming to the desired value.[56] This may, in fact, be what was actually occurring with the MC metrics for the C-5 fleet.

What Should the TNMCM Standard Be?

If the existing standard's equations were used with current C-5 aircraft data (rather than using the 75 percent MC input from AMC for the active duty fleet) to calculate the active duty fleet MC, TNMCS, and TNMCM standards, the resulting standards[57] would be:

- MC Standard = 56.8
- TNMCS Standard = 20.6
- TNMCM Standard = 29.3

These figures are presented for informational purposes only in order to illustrate the stark contrast with the active duty standards in place at the time of the original report's publication (MC = 75, TNMCS = 8, and TNMCM = 24). The study team was not advocating the use of the standards presented above. Instead, the examination presented here and in the study report led to the recommendation that AMC and Air Staff develop a repeatable methodology to compute a standard focused on three things. These three things are listed in the recommendations section of this article. Such a methodology would better align to the original charter from the 2003 CORONA, which was to develop Air Force standards rooted in operational requirements and resources dedicated to the weapon system or MDS.

Conclusions

The process for calculating and establishing Air Force-level TNMCM standards is not well known across the Air Force and not equally applied across the total force. Also, the process currently in use does not produce realistic, capability-based metrics to drive supportable operational decisions.

The process for calculating and establishing Air Force-level TNMCM standards is not well known across the Air Force and not equally applied across the total force. Also, the process currently in use does not produce realistic, capability-based metrics to drive supportable operational decisions.

Recommendations

Develop a repeatable methodology to compute the standard that:

- Reflects day-to-day minimum operational requirements
- Adjusts to fully mobilized force capabilities and surge mobility requirements
- Accounts for historic capabilities and fleet resources

As previously mentioned, the analysis of maintenance metric standards described in this article was developed as part of the larger *C-5 TNMCM Study II*. This is the third and final article in a series related to that particular research. The entire study report can be found at the Defense Technical Information Center private Scientific and Technical Information Network Web site at https://dtic-stinet.dtic.mil/.

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Major Jennifer G. Walston, PhD, USAF

Using AFSO21: The Problem Is Big, Time Is Short, and Visibility Is Enormous

Introduction

When initially assigned to the Air Force CANS project, I wondered what role analysis would play in the effort. Typically, analysts are brought into projects after all the data has been collected and it is time to *analyze*. Most often, this is much too late for the analytic effort to have the optimum impact on the problem and its solutions. However, in this case, the CANS chairman brought me on board at the very beginning. This was a chance to shape the effort and to ensure that a methodical and repeatable analytic process was both followed and documented.

Given this phenomenal opportunity and the fact that I am an operations research analyst by trade, not an AFSO21 expert, why did I choose to use the tools of AFSO21? The simple answer is that it just made sense. When researching applicable industry methods for root cause analysis and risk analysis, the methods that I found most used by industry were available in the *AFSO21 Playbook*. Additionally, because the AFSO21 process is tailorable, we were able to use an industry accepted process and tools while still meeting a very short schedule. The remainder of this article reviews the methodology used in the CANS project.

CANS Methodology

The focus of the CANS methodology was to not only investigate nuclear sustainment and develop solutions, but also to ensure a clear linkage would exist amongst the prioritized findings, root causes, and actionable solutions for implementation.

A team of subject matter experts (SME) was selected, divided into seven subteams, and subsequently consolidated into five working teams as follows:

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In order to ensure that the CANS study produced solutions that addressed the root causes of the problem instead of only treating the symptoms, the team followed a methodical, industry and Air Force accepted, appropriately modified, 5-step problem solving approach called Define, Measure, Analyze, Improve, and Control which worked as a framework, encapsulating the overall solution methodology.

- Organizational structure and lines of authority and responsibility
- Logistics and supply chain management
- Maintenance and storage
- Training and standardization
- Previous report review and research

In order to ensure that the CANS study produced solutions that addressed the root causes of the problem instead of only treating the symptoms, the team followed a methodical, industry and Air Force accepted, appropriately modified, 5-step problem solving approach called Define, Measure, Analyze, Improve, and Control (DMAIC)[11] which worked as a framework, encapsulating the overall solution methodology (see Figure 1). (Please note that at the time of this study, the Air Force had not yet fully adopted the Toyota 8-step problem solving model as the preferred model for AFSO21. For more information, see the AFSO21 Web site.)

Define

The first step of the DMAIC model is to define the problem and develop an improvement project plan.

In this stage, the CANS team built subteam-level charters, defined the scope, and established milestones and roles. Additionally, based on the defined scope, the team developed a comprehensive questionnaire for the team to use during all site visits.

The overall problem was defined and scoped. From the definition, using affinity diagramming, cause and effect diagramming, and brainstorming,[3, 4, 5, 10, 11, 12] the team determined and stratified key mission elements, or focus areas, contributing to the overall problem. These key mission elements are noted as follows:

- **Training.** Activities addressing the level of competence to execute the required job. They include formal training, education, on-the-job training, certifications, and experience.
- **Policy.** Activities that define how the Air Force does business. They should be clear, concise, standard, and relevant.
- **Culture.** Intangibles such as trust, support, accountability, internal and external environment, spirit, politics, pride, personal commitment, perceptions, and tribe mentality.
- **Resources.** People, equipment, systems, facilities, funding, and time.

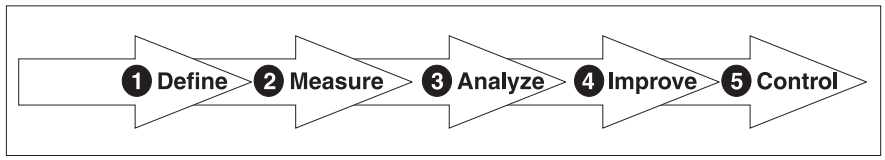

Figure 1. The DMAIC 5-Step Problem Solving Approach[5]

- **Oversight and Control.** Activities that provide feedback on Air Force processes. They include performance measurements and metrics, inspections, closed loop feedback processes, and corrective actions.

Also during this step, the research subteam collected and reviewed over 2,000 documents related to the Air Force nuclear enterprise. From this group of documents, the research team identified 67 key documents and scrutinized previous findings as they related to the key mission areas. It is important to note that the other subteam members were not given access to the previous documents so that the data collection in the site visits would not be biased.

Measure

The second step of the DMAIC model is to measure the existing process and identify the process capability requirement.

The teams collected data through a variety of methods during the measurement step. These methods include the following:

- Site visits consisting of 23 members of the team visiting 31 sites with nuclear capability or related functions
- Personal interviews during site visits, and followup interviews as needed with SMEs
- Research included staff studies, reports, policy, audits, and other sources
- A rapid improvement event addressing the engineering technical support process

Analyze

The process is analyzed to determine its capability. Data is analyzed to identify opportunities for improvement and to develop plans for improving the process. The steps in this phase include root cause analysis, solution development, risk analysis and mitigation, and determining the path forward.

Root Cause Analysis

Root cause analysis was conducted using proven methods, accepted by both industry and the Air Force. Specific methods used included flow diagramming (value stream or process), affinity diagramming, brainstorming, cause and effect diagramming, and the Five Whys. [3, 4, 5, 10,11,12] Brief descriptions of these methods follow.

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- Flow Diagramming (Value Stream or Process Mapping). Value stream mapping (VSM) is a tool to visualize an entire process, such as the flow of material and information as a product or service makes its way through the value stream. It is a good method for displaying relationships between material and information, making waste and its sources visible, setting a common language and basis for discussion, and getting the *big picture*. Value stream mapping differs from process

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mapping in that it is broader in scope, tends to be at a higher level, and is typically used to identify where future focus should occur. The process map shows a process in more detail than a VSM. Such information is useful in analyzing all aspects of a specific process. VSM was used by the engineering team to map out the technical order 00-25-107 maintenance assistance engineering process. Process mapping was used by the engineering team to map out the information flow of the time change technical order process. The CANS team did not perform a full VSM on the entire Air Force nuclear sustainment enterprise due to time constraints. However, the team did use the tool to visualize the highest-level processes of the entire enterprise in order to scope the problem and to view the entire enterprise as one overall process. This was helpful as it highlighted the *seams* to organizations outside of the Air Force and was especially useful in integrating process solutions to non-Air Force processes.

- **Affinity Diagramming.** Affinity diagramming, sometimes called the JK Method for its creator Jiro Kawakito, is useful for organizing and presenting large amounts of data (ideas, issues, solutions, problems) into logical categories based on user perceived relationships and conceptual frameworks. When paired with brainstorming, affinity diagrams can help organize data and ideas, group like items, sort a large number of brainstorming ideas quickly, build consensus, avoid long discussions, stop people from dominating discussions, stimulate independent thoughts, and enable a greater variety of ideas. The CANS team used affinity diagramming when determining the five key mission areas.
- **Brainstorming.** Brainstorming is a problem solving technique in which team members attempt a deductive methodology for identifying possible causes of any problem via free-form, fast-paced idea generation. Brainstorming was popularized by Alex Osborn (advertising executive) in the 1930s, and can be an effective means to develop many ideas in a short amount of time. Brainstorming was used throughout the CANS study.
- **Cause-Effect Diagramming (Fishbone Diagramming).** Cause-effect diagramming, also called fishbone or Ishikawa diagramming, was created by Kaoru Ishikawa in the 1960s as part of the quality movement at Kawasaki Shipyards. It is a visual tool used to logically organize possible causes for a specific problem or effect by graphically displaying them in increasing detail. Additionally, it helps to identify root causes and ensures common understanding of the causes. In this method, a problem statement is written in a box on the right side of the diagram and then possible causes are determined (usually via brainstorming) as categories branching off the problem statement. Benefits include conciseness, adding structure to brainstorming, easily trained and understood, works well in team environments, and the ability to determine and analyze countermeasures. This method was used in determining the five key mission areas and during root cause analysis.
- **The Five Whys.** For root cause analysis, the team used the Five Whys, a well accepted method, first developed by Sakichi Toyoda of Toyota, described by

Taiichi Ohno as "… the basis of Toyota's scientific approach," and is now widely used across industry and within AFSO21. The Five Whys typically refers to the practice of asking, five times, why the failure has occurred in order to get to the root cause or causes of the problem. There can be more than one cause to a problem as well. In an organizational context, generally root cause analysis is carried out by a team of persons related to the problem. No special technique is required.

Using these tools, the hundreds of tactical findings discovered during data collection were analyzed to determine common trends or higher-level issues, which the team chose to call strategic level findings. These findings were then analyzed to determine the root causes. Finally, solutions were developed and then further scrutinized via a *murder board* process to ensure they truly solved the root causes instead of merely symptoms of the real problem.

Risk Analysis

Risk analysis[2,14] and mitigation was performed on each solution using a modified version of the Develop and Sustain Warfighting Systems (D&SWS) Core Process Working Group[13] Active Risk Management (ARM) Process model. Because of the high visibility and importance associated with the correction of the enterprise, the risks of not implementing the solutions were assumed to be known and sufficiently high such that all solutions would be implemented. Thus, the risk analysis in this study focused on the risks associated with implementing the solutions.

These risks were identified and analyzed as follows. The teams identified potential risks to solutions via brainstorming with SMEs by identifying and explicitly defining potential unintended consequences which might occur when the solutions are implemented. These consequences were then scored by the SMEs, via a Delphi voting method, using life cycle risk management likelihood and severity ratings as defined in the D&SWS ARM Process model and shown in Tables 1 and 2. (Note that the CANS team focused on performance impact as the most critical characteristic. Each proposed solution was reviewed on the basis of consequence, vice cost or time to implement.)

Notional risk analysis output is shown in Figure 2, where the green squares identify a safe area where there is little likelihood of a risk occurring and low impact to the system if it does. Similarly, the yellow and red squares identify medium and high risk areas, respectively. The line is calculated by measuring the full range

1	Not Likely	1% - 20%
2	Low Likelihood	21% - 40%
3	Likely	41% - 60%
4	Highly Likely	61% - 80%
5	Near Certainty	81% - 99%

Table 1. Consequence Likelihood Ratings[13]

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Once defined, a multi-objective optimization problem can be solved via many methods. The particular method selected can depend on many factors including, but not limited to, the complexity of the problem, the time allowed for problem solution, the availability and quality of information, and the preferences of the decisionmaker. In this case, an a priori scalar method called weighted-sum-of-the-objective-functions was selected.

of the yellow area (medium impact) and determining the 98 percentile point. The team determined that the +98 percentile data points (within the medium area), could have very easily been scored within the red area (high impact) relative to the error margins within the scoring process and should be treated as high risk. Thus, solutions with risks above and to the right of this line required additional review by the teams to determine risk mitigation strategies.

Prioritization via Multi-Objective Optimization

To determine a prioritized order, the strategic level findings were scored on their impact, if solved, on the five key mission areas. The result was then modeled as a multi-objective optimization problem in which five key mission areas represent the competing objectives and the prioritized order of the strategic findings represents the decision variable. In this type of problem, there often exists no single criterion for choosing the best solution. In fact, even the notion of *best* can be unclear when multiple objectives are present; and in many cases, it can be shown that improvement to one objective actually degrades the performance of another.[1]

The multi-objective optimization problem,

$$\min F(x)$$

subject to

$$x \text{ e } V5\{0,1)^n : g_i(x) \leq 0,\ i = 1,2,\ldots, M\}$$

where $F{:}\{0,1\}^{\prime\prime} \longrightarrow R^J$, *is that of finding a solution* x^n e V that optimizes the set of objectives $F = (F_1, F_2, \ldots, F_J)$ *in the sense that no other point y* e V yields a better function value in all the objectives.[15] (Note the precise mathematical definition of x^n *can be found in Ehrgott*[8]*)* The point x is said to be *non-dominated*, *efficient*, or *optimal in the Pareto sense*.[9] The (typically infinite) set of all such points is referred to as the *Pareto optimal set* or simply the *Pareto set*. The image of the Pareto set is referred to as the *Pareto Frontier* or *Pareto Front*. If the Pareto set (or corresponding Pareto front) results from a solution algorithm and is not exact, it is referred to as the *approximate* (or *experimental*) *Pareto set* or *approximate* (or *experimental*) *Pareto front*, respectively.

Once defined, a multi-objective optimization problem can be solved via many methods. The particular method selected can depend on many factors including, but not limited to, the complexity of the problem, the time allowed for problem solution, the availability and quality of information, and the preferences of the decisionmaker. In this case, an *a priori* scalar method called weighted-sum-of-the-objective-functions (WSOTOF) was selected. As the name implies, this method combines the various objectives via a convex combination (a weighted sum). Though it is among the simplest of the multi-objective methods, it is guaranteed to produce an efficient solution (see Lemma 3.3.11 in Walston[19]). It should be noted that this method is not guaranteed to find all possible solutions, particularly if the corresponding Pareto front is non-convex;[6,7,16,17] however, in this particular case, the benefits of simplicity and speed far outweigh potential risks associated with examining only a portion of the Pareto front.

	DoD Guide	Proposed Air Force Definition
1	Minimal or no consequence to technical performance	Minimal consequence to technical performance but no overall impact to the program success. A successful outcome is not dependent on this issue; the technical performance goals will still be met.
2	Minor reduction in technical performance or supportability, can be tolerated with little or no impact on program	Minor reduction in technical performance or supportability, can be tolerated with little impact on program success. Technical performance will be below the goal, but within acceptable limits.
3	Moderate reduction in technical performance or supportability with limited impact on program objectives.	Moderate shortfall in technical performance or supportability with limited impact on program success. Technical performance will be below the goal, but approaching unacceptable limits.
4	Significant degradation in technical performance or major shortfall in supportability; may jeopardize program success.	Significant degradation in technical performance or major shortfall in supportability with a moderate impact on program success. Technical performance is unacceptably below the goal.
5	Severe degradation in technical performance; cannot meet KPP or key technical/supportability threshold; will jeopardize program success	Severe degradation in technical/supportability threshold performance; will jeopardize program success.

Table 2. Risks

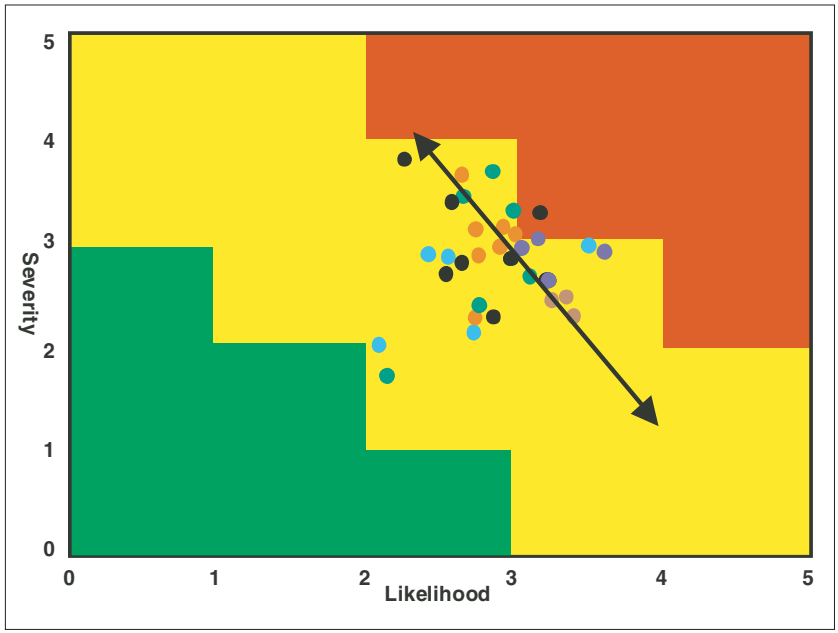

Figure 2. Notional Risk Analysis Output

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Once the objectives have been combined, any applicable optimization method can be used to determine the prioritized list of findings.

To combine the objectives, the WSOTOF method requires a predetermined set of weights. In many cases, this can be problematic[18] as it is dependent on subjective judgment of the decisionmaker which may not be available or fixed across the duration of the study. Thus, this step is of particular importance. Additionally, in this particular problem, the determination of weights is even more complex as there are multiple decisionmakers to be considered.

To ensure that multiple decisionmaker preferences are included and considered in the solution, the following method was used. First, a group of senior Air Force leaders was identified as stakeholders for the nuclear sustainment enterprise and defined as the decisionmakers for the multi-objective problem. After each stakeholder provided a set of weights, the problem was solved as follows:

- A simple average of the weights provided by the stakeholders was used as the weights for the problem. However, there was considerable variance in the weighting schemes provided by the stakeholders (see Figure 3 and Table 3) indicating that further investigation was necessary. The distribution of the weights was tested for normality using normal p-p plots and the Kolmogorov-Smirnov (K-S) goodness test for normality. The plots and the K-S test indicate failing to reject the null hypothesis that the weights are normally distributed. Though in this case, parametric statistics would then be applicable, the use of a simple mean may not be adequate because of the high degree of variance.
- The weights were further analyzed as follows. A sensitivity analysis was conducted to determine the impact of the weighting scheme on the overall prioritized solution. It was found that the top priority issues in the prioritization solution were relatively impervious to the weighting scheme. A prioritized list of findings was determined for each decisionmaker's preference of weights and was then examined against the others. In this case, it was also found that the top priority issues did not vary much over the various weighting schemes. The average of the ranks assigned from each weighting scheme was determined for each finding, and was used to assign its final rank.

Once the objectives have been combined, any applicable optimization method can be used to determine the prioritized list of findings. In this case,

	N	Minimum	Maximum	Mean	Standard Deviation	Variance
Training	31	5	40	22.16	7.267	52.806
Policy	31	10	50	21.77	8.995	80.914
Culture	31	5	35	16.06	8.668	75.129
Resources	31	5	40	22.52	8.282	68.591
Oversight/Control	31	5	30	17.48	5.591	31.258
Valid N (listwise)	31					

Table 3. Descriptive Statistics

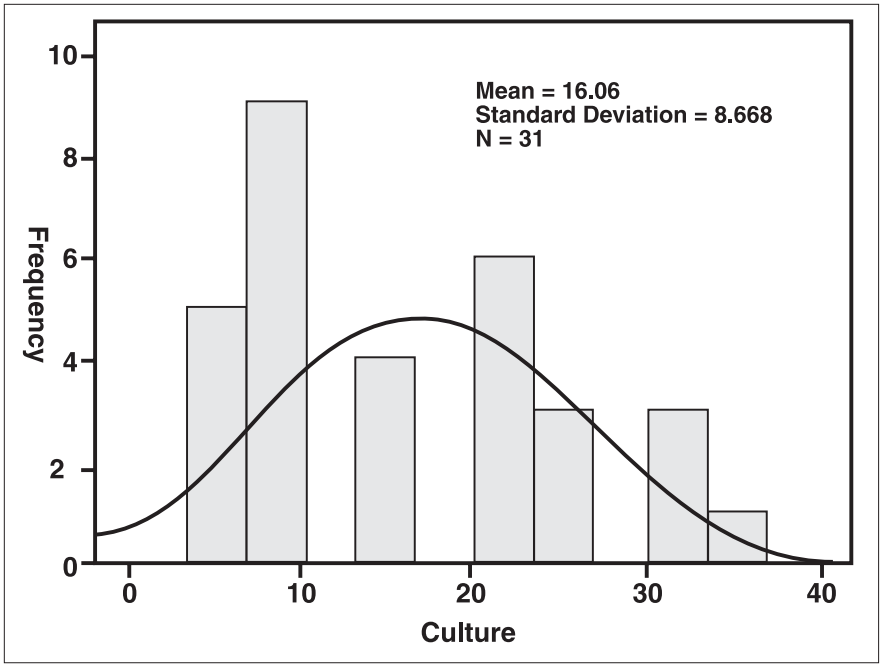

Figure 3. Histogram of Weights Assigned to Culture

because no constraining information was identified, and impact to the overall problem statement was the sole criteria for selection, a simple greedy heuristic method was used. Simply stated, once the weights are determined, the *value* of solving each particular finding becomes clear, and the prioritized list follows directly.

Cost Analysis

The CANS cost team estimated costs for solutions that required funding. Cost analyst support upfront was critical to providing leadership with vital financial information. As solutions were identified, the cost team worked to define tasks, timelines, and associated costs. Identifying and linking costs with solutions allows leadership to make timely, informed decisions with known costs. In this case, costs of the CANS solutions totalled $25.6M for fiscal year 2008—the process worked and our leadership provided the funding to fix the problems because the methodology was solid.

Improve. During the Improve step, the plan that was developed in the Analyze phase is implemented. The results of the change are evaluated and conclusions are drawn as to its effectiveness. This can lead to documenting changes and updating new instructions and procedures.

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Using AFSO21: The Problem Is Big, Time Is Short, and Visibility Is Enormous

The foundation of the CANS analysis was the aggressive use of AFSO21 tools to attack root causes.

The CANS chairman was given authority to immediately implement some solutions. There were six *just-do-it* solutions. The remaining results of this team's efforts were presented to senior leaders in a number of briefings at the major commands and Air Staff.

Control. Control plans were developed to ensure the process is institutionalized and continues to be measured and evaluated. This can include implementing process audit plans, data collection plans, and plans of action for out-of-control conditions, if they occur.

This study team worked concurrently with SAF/IG (Secretary of the Air Force, Inspector General's office) and AF/A9 (Studies and Analyses, Assessments, and Lessons Learned Directorate) to develop inspection and assessment criteria and plans to assess the status of the Air Force nuclear sustainment enterprise and measure the progress of addressing the CANS findings.

Conclusion

The foundation of the CANS analysis was the aggressive use of AFSO21 tools to attack root causes. Though the effort was time constrained and many of the processes were modified to streamline the application, this did not detract from the effort, and actually enhanced the team's ability to use those portions of AFSO21 that made sense. Overall, the CANS effort highlights the power, flexibility, applicability, and simplicity of the AFSO21 toolkit and is a resounding success story.

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Captain Alice Marie Long, USAF

Enterprise Architecture: Origins, Tools, and Insights

Introduction

The Air Force is continually taking measures to institutionalize enterprise architecture (EA). However, many in the Air Force have a limited concept of what an EA is, how it works, and most importantly, why it is needed. The purpose of this article is to discuss these key questions, to present some guidelines for implementation of EA, and make the reader aware of some of the possible pitfalls of EA development.

To begin a discussion of enterprise architecture, it is important to first obtain an understanding of architecture in general. Architecture is the structure of components, their relationships, and the principles and guidelines governing their design and evolution over time.[1] Architecture is known to be essential when considering the design of a new building or a community; however, architecture is equally necessary when considering the design and creation of complex systems within organizations. Whether a new community is being planned or a business is expanding, several of the same issues must be considered: integrated services, interoperable systems, and efficient operations. The end objective of architecture is the alignment of components under common standards that facilitate change management and ensure integrated and effective operation.

The concept of architecture is comparable at the enterprise level. The Federal Chief Information Officers (CIO) Council regards an enterprise as an organization supporting a defined business scope and mission and comprised of interdependent resources (people, organizations, and technology) who must coordinate their functions and share information in support of a common mission (or set of related missions).[2] Enterprises exist within commercial businesses and industry, private institutions, as well as in areas of governance. Governmental

The federal government is a single enterprise with shared strategic objectives, a common authority structure, integrated management processes, and consistent policies. As is the case in other enterprises, the goal is to optimize resource allocations across the organization to achieve common goals, whether at the local or national level.

enterprises are unique because their purpose is not the generation of revenue. These organizations are concerned primarily with the maintenance of basic security and public order. Nevertheless, the federal government is a single enterprise with shared strategic objectives, a common authority structure, integrated management processes, and consistent policies. As is the case in other enterprises, the goal is to optimize resource allocations across the organization to achieve common goals, whether at the local or national level.[3]

Legislation

Aside from simply being a good tool for business, architecture within the government has been mandated by legislation. In 1996, the *Clinger-Cohen Act* (CCA) was established to improve the way the federal government acquires and manages information technology (IT). The idea was that acquisition, planning, and management of technology should be treated as a capital investment, exactly as a profitable business would be operated. The CCA directs all federal agencies to establish a comprehensive approach to manage the acquisition, use, and disposal of IT. Though architecture is not prescribed by name in the CCA, it does promote a coordinated, interoperable, secure, and shared governmental infrastructure.[4] A legislative measure that formally mandates the development of architecture for government programs is described in Circular A-130, *Management of Federal Information Resources*. This publication prescribes the development and maintenance of an enterprise architecture to promote the appropriate application of federal information resources.[5] This mandate is intended to establish capital planning and investment control processes that link mission needs, information, and IT in an effective and efficient way. The circular also establishes architecture as *grading* criteria for acquisition of new systems. In that, architecture is used for the certification of any federal business system modernization effort that exceeds $1M.[6]

One of the most significant Department of Defense (DoD) level instructions is Chairman of the Joint Chiefs of Staff Instruction 3170.01, *Joint Capabilities Integration and Development System* (JCIDS). JCIDS is intended to identify shortfalls and redundancies in national defense and to develop solutions (materiel and nonmateriel) through a joint collaboration using integrated architectures among the Services. The focus is to resolve military capability gaps with solutions that are *born Joint* with architecting consideration given to uses across the spectrum, not a single Service or mission area. The future state of JCIDS implementation is fully integrated defense networks that eliminate waste and optimize system usage.[7] There are several other DoD directives governing the use of architecture, but at the Air Force level, enterprise architecture is prescribed in Air Force Policy Directive 33-4, *Enterprise Architecting*. The directive assigns architecture development and management, a governance process, as well as the establishment of a repository for architecture products. The Air Force enterprise architecture is to be used as a decision support tool, and guide all IT and National Security System investments.[8]

Architecture Frameworks

To facilitate the completion of required architecture, a framework is necessary. A framework addresses architecture components, such as methodology, product descriptions, reference models, categorization, and classification. An overview of the most common architecture frameworks follows.

The Zachman Framework

One of the first and best known standards for classifying the descriptive models that comprise enterprise architecture is the Zachman Framework. This methodology was based on the belief that a common architectural schema could be used to represent any complex entity. It is depicted as a grid (see Figure 1) that consists of six functional focuses (columns), and then considers those focuses from the perspectives of the stakeholders (rows). The Zachman Framework does not prescribe a particular architecting methodology, and is used to categorize primitive enterprise architecture information. However, the tool can be used to organize data on the enterprise, to define which artifacts to produce and to describe processes.[9] Zachman

	What	How	Where	Who	When	Why	
Scope	Inventory Identification: Inventory Types	Process Identification: Process Types	Network Identification: Network Types	Organization Identification: Organization Types	Timing Identification: Timing Types	Motivation Identification: Motivation Types	Strategies
Business	Inventory Definition: Bus. Entity Bus. Relation	Process Definition: Bus. Transform Bus. Input	Network Definition: Bus. Location Bus, Connect	Organization Definition: Bus. Role Bus. Work	Timing Definition: Bus. Cycle Bus. Moment	Motivation Definition: Bus. End Bus. Means	Executive Leaders
System	Inventory Representation Sys. Entity Sys. Relation	Process Representation Sys. Transform Sys. Input	Network Representation Sys. Location Sys. Connect	Organization Representation Sys. Role Sys. Work	Timing Representation Sys. Cycle Sys. Moment	Motivation Representation Sys. End Sys. Means	Architects
Technology	Inventory Specification: Tech. Entity Tech. Relation	Process Specification: Tech. Transform Tech. Input	Network Specification: Tech. Location Tech. Connect	Organization Specification: Tech. Role Tech. Work	Timing Specification: Tech. Cycle Tech. Movement	Motivation Specification: Tech. End Tech. Means	Engineers
Component	Inventory Configuration: Comp. Entity Comp. Relation	Process Configuration: Comp. Transform Comp. Input	Network Configuration: Comp. Location Comp. Connect	Organization Configuration: Comp. Role Comp. Work	Timing Configuration: Comp. Cycle Comp. Moment	Motivation Configuration: Comp. End Comp. Means	Technicians
Operations	Inventory Instantiation: Ops. Entity Ops. Relation	Process Instantiation: Ops. Transform Ops. Input	Network Instantiation: Ops. Location Ops. Connect	Organization Instantiation: Ops. Role Ops. Work	Timing Instantiation: Ops. Cycle Ops. Movement	Motivation Instantiation: Ops. End Ops. Means	Workers
	Inventory	Process	Network	Organization	Timing	Motivation	

Figure 1. Zachman Enterprise Architecture Framework

applied to the Air Force logistics enterprise would include an organization chart to define the high level *who* portion of the framework. At a lower level would be a description of the physical data resident in the logistics enterprise. This framework would be helpful in defining and describing processes associated with the logistics enterprise and provide a good way to determine which artifacts are necessary to model the system.

The FEA is comprised of an interrelated set of five reference models, all focused on developing a common language for the enterprise.

The Open Group Architecture Framework

Another framework that provides a detailed comprehensive approach to design, planning, and implementation of architecture is The Open Group Architecture Framework (TOGAF). TOGAF is designed to support four common subsets of an overall enterprise architecture: business architecture, data architecture, application architecture, and technology architecture. This method originated from the Technical Architecture Framework for Information Management developed by DoD. TOGAF is an architectural process that can be used to complement Zachman's taxonomical approach. Like Zachman, however, TOGAF does not prescribe architecture products, but instead promotes an architecture development method (ADM) that gives guidelines for architecting. The stages of the development cycle outlined in the ADM provide guidance to the architect. These phases are further decomposed into steps. The ADM cycle is an iterative process, requiring frequent validation of results against the original expectations.[10]

The Federal Enterprise Architecture

A third architecture framework is tailored to a more specific enterprise; the federal government. The federal enterprise architecture (FEA) is a business approach aimed at developing a more customer focused government that simplifies processes and unifies efforts across agencies. The FEA has evolved from its original form, with significant changes occurring in 2007 and 2008. Currently, three core principles guide the strategic direction of the FEA: the federal enterprise must be business driven, proactive, and collaborative across the federal government; and the architecture must improve the effectiveness and efficiency of government information resources (see Figure 2).[11]

The FEA is comprised of an interrelated set of five reference models, all focused on developing a common language for the enterprise. The first model is the Performance Reference Model (PRM). The PRM is a performance measurement focused on the business of government at a strategic level and assesses the impact of IT investments at this level. It is designed to show the link between inputs and outputs, as well as to identify the practices of effective and efficient organizations within the enterprise. This type of analysis facilitates decisionmaking regarding resource allocation.

The next model is the Business Reference Model (BRM). This model facilitates a functional view of the enterprise rather than an organizational one. Standard

business capabilities are identified without regard to what agency is completing them, and a business functions view is defined. The importance of this model lies in proper implementation. The BRM must be incorporated into the architectures and management processes of governmental agencies in order to help accomplish strategic goals of the enterprise.[11]

The Service Component Reference Model (SRM) is a business driven, functional framework used to classify individual service components according to how they support both the performance and business objectives. The SRM helps to recommend service capabilities that will maximize reuse of business and technical capabilities. The Technical Reference Model is a component-driven model that categorizes standards and technologies. Again, the focus is to identify and reuse the best solutions.

Finally, the Data Reference Model (DRM) is a more flexible, standards-based model that facilitates information sharing among government agencies. The DRM objective is the standardization of data management processes across federal, state, and local organizations as necessary to enable the repeatability of the best processes across agencies by establishing a common language. In support of this objective, DRM contains three standardization areas: data description, data context, and data sharing.[11]

Another issue critical to FEA is the measurement of success. Federal agencies are rated in three main capability areas: completion, use, and results. The completion capability area measures the completion maturity of an EA's artifacts with respect

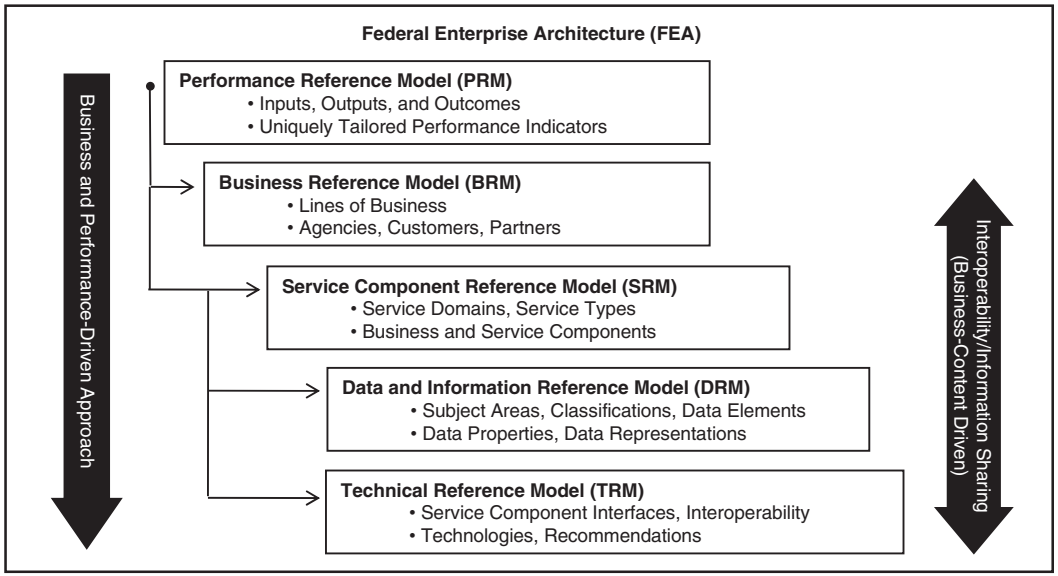

Figure 2. FEA Reference Models

AFPD 33-04 establishes the AFEA as the method for managing change and understanding complexity in the Air Force environment. The AFEA is ultimately intended to act as a tool to aid in decisionmaking through supporting key decisionmaking processes

to performance, business data, services, and technology. The enterprise's architectures should be well-defined and show traceability among the layers of architecture and artifacts. The use capability area deals with the actual implementation and use of the architecture as it measures the policies and procedures necessary for an organization to develop and manage its EA. The results capability area measures the effectiveness and value of the EA by assigning performance measurements to the EA processes and using these measures to complete analysis of the architecture. The results of this analysis are used to update practices and guidance for the EA. Following measurement in each of these three areas, agencies are assigned a *success rating* based on a green, yellow, and red coding system.[12]

DoD Architecture Federation

Figure 3 depicts the architecture federation of the federal government as it pertains to the Air Force specifically. It is relevant to note the horizontal portions of Figure 3. Each Air Force component is broken down into three subenterprises: agile combat support, warfighting, and infrastructure. The Air Force decomposition is further depicted in Figure 4, showing several mission and major command (MAJCOM) architectures. The Air Force Logistics Enterprise (LogEA) is a subenterprise of the agile combat support mission, and evaluation of the LogEA architecture products is one of the newly chartered mission areas of the Air Force Logistics Management Agency (AFLMA). The AFLMA is charged by A4I (Directorate of Transformation) with guaranteeing compliance of architecture to prescribed standards, and eventual management of the LogEA.

Air Force Enterprise Architecture and the DoD Architecture Framework

The vertical columns of the Federal Architecture Federation depict the guidance setting architecture requirements for the DoD and the individual military services. As seen here, the Air Force has its own enterprise architecture framework (AF EAF). The AF EAF uses the same reference models as the DoD's FEA, but provides context focused on Air Force strategy and missions. The correlation between the FEA and the AFEA is illustrated in Figure 4.

AFPD 33-04 establishes the AFEA as the method for managing change and understanding complexity in the Air Force environment. The AFEA is ultimately intended to act as a tool to aid in decisionmaking through supporting key decisionmaking processes (capabilities based planning and analysis; planning, programming, budgeting, and execution; acquisitions; and portfolio management), and guiding all IT and National Security Systems investments. Additionally, the AFEA assigns responsibility for the development, evolution, and management of the EA, and institutes a governance process. Air Force MAJCOMs directed to establish enterprise architectures must institute policies, procedures, and

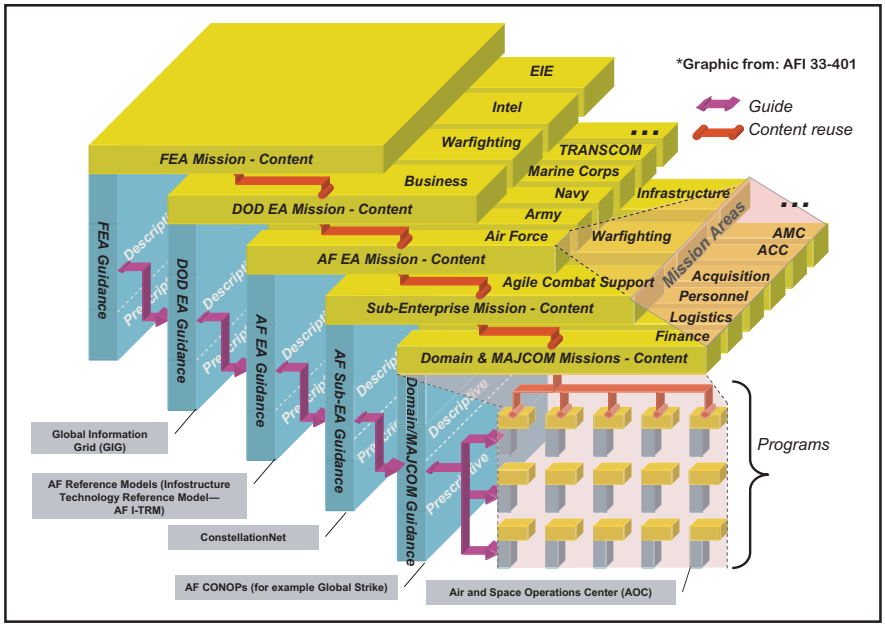

Figure 3. Federal Architecture Federation

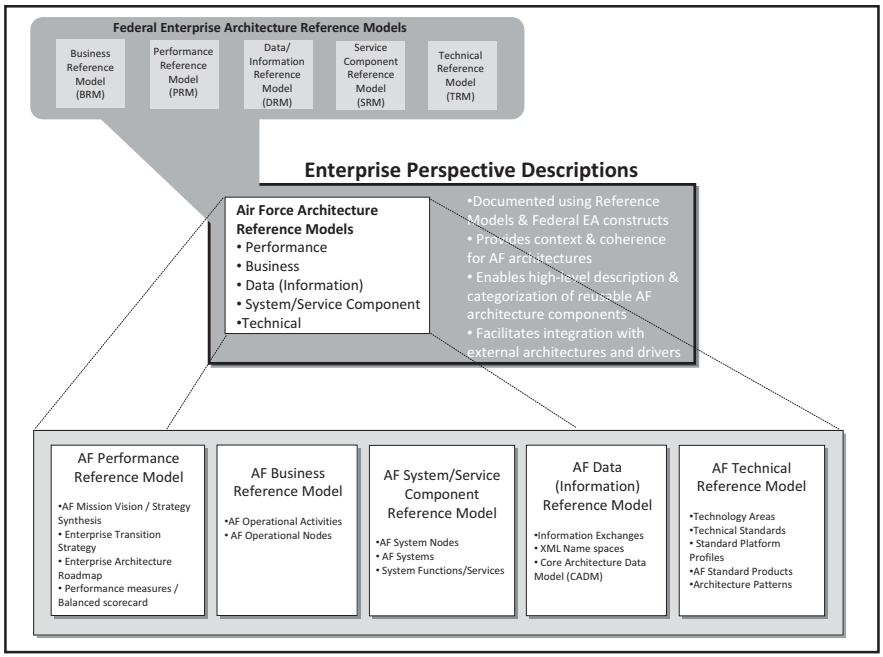

Figure 4. Air Force Enterprise Architecture Framework

Enterprise Architecture: Origins, Tools, and Insights

The architectural products outlined in the DoDAF flow naturally from the reference models contained in the FEA, and subsequently the AFEA. The relationship between the AFEA and DoDAF is seen in the developing Air Force LogEA.

guidelines for architecture activities, appoint an architect, and develop and maintain architecture products. Throughout this process these products must be approved and certified as prescribed in Air Force Instruction 33-401, *Implementing Air Force Architectures.*

It was determined by the Defense Science Board that one of the key means for ensuring military systems are interoperable and effective is to establish comprehensive architecture guidance for the entire DoD.[13] The Department of Defense architecture framework (DoDAF) was developed to give direction as to how architecture products should be developed.

The DoDAF is an evolution of the Air Force command, control, communications, computers, intelligence, surveillance, and reconnaissance (C4ISR) architecture framework which originally addressed the interoperability of C4ISR specific capabilities. It consists of three volumes. Volume I offers a general overview of the DoD architecture concept and provides guidance for the development and management of DoD architectures. Volume II delves more deeply into the concept, outlining the specific details for the individual framework products. Finally, Volume III shifts in focus to the data for architecture and its uses. The overarching DoDAF structure is organized into four unique views: all (AV), operational (OV), systems/services (SV), and technical standards (TV). The architecture products associated with each of these views serve specific purposes.

The OV captures the operational nodes of an architecture, their tasks and activities, and interactions and information exchanges required to accomplish DoD operational concepts. The SVs outline the physical systems, required system functionality, and their data exchanges for supporting the operational views. As the architecture matures, the TVs are needed to communicate standards, protocols, technologies, and interfaces to ensure the system will satisfy its operational requirements. Though not depicted in the graphic below, the AV represents aspects of the architecture related to all three views. While the AV products don't present a distinct view of the architecture, they provide information relevant to the architecture as a whole (see Figure 5).[13]

The architectural products outlined in the DoDAF flow naturally from the reference models contained in the FEA, and subsequently the AFEA. The relationship between the AFEA and DoDAF is seen in the developing Air Force LogEA. One of the DoDAF architectural models representing the Performance Reference Model is the AV-1. In LogEA, this product acts as a concept of operations, providing strategic level information including assumptions, constraints, and limitations of the logistics enterprise. Representations of the Business Reference Model are the OV-5 activity models. The OV-5 describes the operations that are generally conducted in the course of executing the logistics mission. The DoD supply chain materiel management regulation 4140.1 outlines the primary activities resident in the logistics enterprise high-level OV-5; Plan, Source, Make, Deliver, and Return. All lower level activities in the logistics supply chain result from

decompositions of these key activities. The Air Force Systems/Service Component Reference Model is represented in the DoDAF SVs. For LogEA, the Systems/Services views are resident in the Expeditionary Combat Support System—the system that supports the logistics supply chain.

Observations and Case Studies

The frameworks presented here employ different approaches to architecture. While each method has its own focus, some frameworks could be used in complementary ways, and the combination of methodologies can result in synergistic effects. For example, TOGAF describes how to architect. Products outlined in the DoDAF could be employed to document the architecture decisions made in TOGAF methodology. The Zachman Framework can be used to check for completeness in architectural elements and to determine whether or not processes are sufficiently examined. This type of combination often provides a better result than attempting to fit everything into a single framework. The important issue is to find the method (or methods) that works well within the organization's goals and constraints, always keeping in mind that the focus of using these tools is to unite the resources of the enterprise, and not to overcomplicate the effort.

Though an overarching view of EA has been presented, the concepts and various methodologies can still seem a bit nebulous. A few case studies where enterprise architectures have been implemented will now be examined. The hope is to clarify and give relevance to the discussion, and to highlight the realized advantages as well as some of the difficulties associated with architecture implementation. The following examples illustrate uses of EA within government agencies.

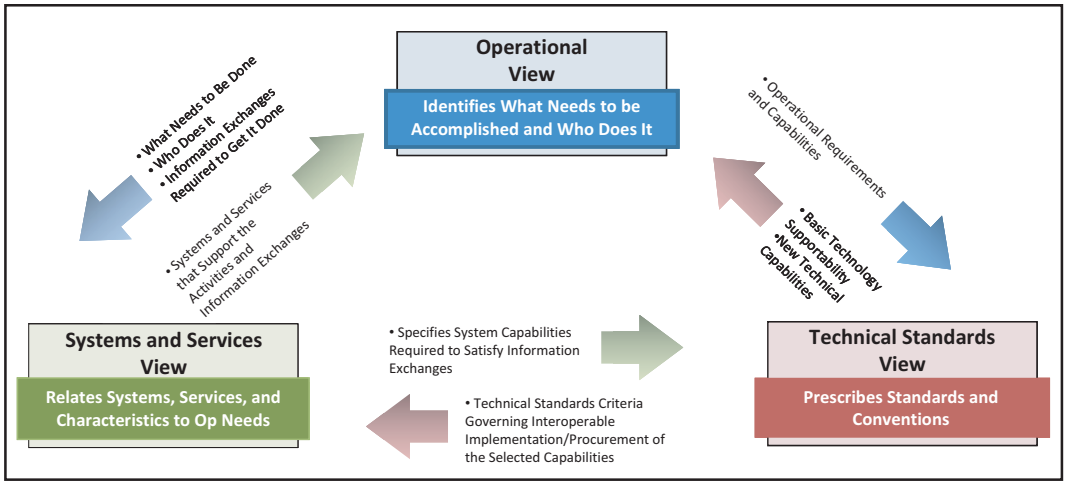

Figure 5. DoDAF Views and Linkages

Enterprise Architecture: Origins, Tools, and Insights

Though a significant investment was made to develop and maintain an enterprise architecture, benefits were soon realized. The budget for the maintenance of the EA is $350K to $500K annually, but the FDA projected a $10M savings over the first 5 years. This savings comes primarily from eliminating redundant IT costs.

Case 1

The Food and Drug Administration (FDA) is the operating division of the Department of Health and Human Services (HHS), and is charged with ensuring foods, drugs, and cosmetics are safe and properly labeled; drugs and medical devices are safe and effective; blood is safe and in adequate supply, and equipment that uses radiant energy is safe.[14] In response to the President's 2002 Management Agenda, the HHS established its own initiative to consolidate, streamline, and standardize administrative programs. The FDA faced a few key challenges associated with the mandate: necessary alignment of information technology with business strategy, limited funding and resources, lack of standardized processes, and a culture resistant to change.[15]

The FDA began by adding a chief enterprise architect (CEA) position to its strategic IT management staff to oversee this undertaking. The CEA established an EA working group made up of representatives from each of the eight FDA center offices. Technical training was required to ensure personnel could adequately build and use EA frameworks, so representatives from the center offices received Federal Enterprise Architecture certification. The FEA reference models were chosen for architecture development in order to facilitate cross-agency analysis and the identification of duplicative investments, gaps, and opportunities for collaboration within and across the agency. The resulting products created a standardized architecture framework which served as a foundation to develop both baseline and future target EAs. Common governance structures were defined, ensuring each of the departments supported the FDA's goals and objectives. Additionally, an office of shared IT services was developed to provide better alignment between business and IT. This helped the agency to reuse and consolidate applications where possible. This office also enabled the FDA to track IT investments across the entire enterprise.

Though a significant investment was made to develop and maintain an enterprise architecture, benefits were soon realized. The budget for the maintenance of the EA is $350K to $500K annually, but the FDA projected a $10M savings over the first 5 years. This savings comes primarily from eliminating redundant IT costs. The infrastructure now helps to drive consolidation activities across the enterprise. With the transparency of the system, communication and efficiency were improved, leading to improved decisionmaking as well.[14]

The FDA provides a good example of enterprise architecture implementation. Today, the EA working group acts as a review board, selecting IT investments based on the FDA mission and objectives. As a continuing component of the IT strategy, the FDA's EA framework is reducing costs, and improving mission performance.

Case 2

The next case study involves US Customs and Border Protection (CBP). CBP is a component of the Department of Homeland Security and is primarily responsible for keeping terrorists and their weapons out of the US. The scope of this mission is

threefold: covering border control, trade, and travel within the US. Presently, CBP employs 41,000 personnel who enforce hundreds of US regulations, including immigration and drug laws.[16]

Not all implementations of enterprise architecture are as clear-cut or initially successful as the FDA example. CBP encountered significant problems in earlier stages of its architecture development. Beginning in 1997, the US Customs Service planned to invest over $1B in a modernization effort to create an automated commercial environment (ACE) focused on certain core missions. In 1999, the Government Accountability Office (GAO) found that CBP was not managing this effort in a cost effective way. The GAO found serious weaknesses in architectural definition, investment management, and software development and acquisition. It was recommended that Congress withhold funding until these deficiencies were resolved.

CBP began preparing a new strategy starting with the development of the US Customs Modernization Program management organization. The organization is charged with establishing an EA systems concept for the ACE. The goals of the concept were to govern the modernization processes, align investments with strategic goals, and turn the CBP into a more performance based organization. A task force consisting of a planning group and a technology and architecture group (TAG) were created. The TAG was responsible for developing the enterprise architecture. The EA was a collaborative effort and involved stakeholders from each CBP business unit. A cost analysis, along with a metrics program to measure the benefits of implementing the EA was considered from the onset. The GAO worked in conjunction with CBP, validating their efforts throughout the process.

Not all implementations of enterprise architecture are as clear-cut or initially successful as the FDA example. CBP encountered significant problems in earlier stages of its architecture development.

CBP's architecture ensures that IT investments are properly aligned with the architecture. Similar to the FDA, focus was placed on increasing IT standardization, minimizing duplication, providing better justification for IT spending, increased efficiency, and better responsiveness to customer needs. CBP produced the architecture using the four FEA reference models, and System Architect was used for modeling purposes. Further, the EA framework has evolved and, like the Air Force's AFEA, an enterprise-specific Treasury Enterprise Architecture Framework (TEAF) now defines all artifacts contained in the CBP EA.

CBP met with many of the same obstacles to architecture implementation as did the FDA. Initially, a major culture change was required within IT. Systems developers were not optimistic about compliance with new processes, standards, and controls. Development of an EA was also a major time commitment, taking 18 months to realize the initial functioning EA. There was also an upfront cost of $5M associated with the effort, and a continuing cost of $2M annually to update and maintain the EA.

Though CBP had a rocky start in developing EA, eventually the management weaknesses identified by the GAO were resolved and funding was restored. In addition to this, benefits are now realized. Evaluation processes have confirmed that over a

$30M return on investment has been made, with over $5M of these savings resulting from the elimination of duplicative systems. The IT infrastructure is much less complex now, and stovepiping of data, technology, and systems has been eliminated. Finally, change management is also facilitated, with the development of a *to be* architecture blueprint ushering in several new systems acquisitions.

Several transformation initiatives have been implemented as part of the EA execution plan. This campaign, known as Expeditionary Logistics for the 21st Century, is intended to capture both the future vision and the transformation path for the Air Force logistics enterprise.

Air Force Logistics Enterprise Architecture and the AFLMA

The AFLMA was recently given responsibility for the evaluation of LogEA. LogEA is intended to guide the transformation of the Air Force supply chain, and to stand as the single authoritative source of process and system models for this logistics chain. The current system must evolve into a rapid response, dynamically reconfigurable, integrated network, supporting the expeditionary aerospace forces (EAF) concept at home and in deployed locations.[17] Ultimately, the intent of LogEA is to deliver mission capability while maintaining affordability.

Several transformation initiatives have been implemented as part of the EA execution plan. This campaign, known as Expeditionary Logistics for the 21st Century (eLog-21), is intended to capture both the future vision and the transformation path for the Air Force logistics enterprise. LogEA is the operational and systems architecture that will communicate and guide the vision of the eLog-21 campaign.[16] The impact of these eLog-21 initiatives is measured against the high-level goals to improve operational capability while minimizing costs.

The elog-21 transformation initiatives are divided into 11 cost categories.

- Depot maintenance
- Depot level reparable
- Aviation fuels
- Consumables
- Sustaining engineering
- Contract service
- Military personnel
- Civilian personnel
- Software maintenance
- Other operations and maintenance
- Critical space operations

Each of the eLog-21 initiatives is classified as IT or non-IT, and architecture requirements are determined according to this classification. Artifacts are submitted to AFLMA for a review to verify LogEA compliance, according to the published LogEA Compliance Plan. The result of this process is an integrated set of enterprise-

wide priorities which will reduce costs by improving the planning and execution of procurement and production activities.[16]

Challenges

It is clear that the lack of a system architecture can contribute to increased costs and subsystem problems, but even in successful architecture developments, common difficulties seem to arise. As the AFLMA manages LogEA, it is valuable to highlight some of these challenges.

Strategy

The cornerstone of a successful architecture begins with a strategic vision. This point is reflected in the AFEA Performance Reference Model. This model prescribes a roadmap for the entire architecture development as well as performance measures to calculate the success of the effort. This involves well-defined direction from the key sponsors and stakeholders that is directly traceable to the Air Force mission area under consideration. As illustrated in the case studies, the vision and scope for both efforts were clear, and architecting teams had focus and, most importantly, a shared concept of the effort. The CBP case study specifically illustrates the implementation of performance measures and metrics to calculate the benefit of implementing architecture. Cost/benefit analysis is a vital point in the decision to develop architecture. An organization must be willing to invest in the underlying organizational and cultural structures to support the EA, and be absolutely certain that these investments will pay dividends in the future.

It is clear that the lack of a system architecture can contribute to increased costs and subsystem problems, but even in successful architecture developments, common difficulties seem to arise.

Culture and Senior Commitment

Senior stakeholder commitment is also essential to initiating architecture development. Though policy direction ensures commitment from Air Force leadership regarding architecture development, other associated issues arise. It is crucial that organizations are creating artifacts with the strategic vision in mind and not simply to fulfill requirements and meet deadlines. The purpose of architecture can be summed up in one idea: optimizing limited resources. If focus shifts from this idea to simple fulfillment of requirements, the benefits of architecture will never manifest. To help guarantee effectiveness, the mandate to develop enterprise architecture should also provide for resources toward additional personnel, education, and training for those developing and evaluating architecture, and reasonable deadlines. Ideally, enterprise architecture development should focus first on understanding the existing process (as-is), and then the desired future state (to be). This practice lends support to the change management capability of EA. Products should be incremental and iterative, not a static set of artifacts to be archived and then forgotten.

Cost

With these ideas in mind, another issue comes to light; that is, architecture costs money. As shown in the case studies, both the FDA and CBP established a start-up

The institution of enterprise architecture has emerged as common practice within commercial industry and is mandated now for all federal enterprises. Though enterprise architecture is not a topic requiring expertise for every member of an organization, it is valuable to have a fundamental understanding of what it is and why it is being used.

budget as well as an annual maintenance budget for development and continuing management of the EAs. Many eLog-21 initiatives employed contractor support for architecture development. Attention should also be given to sustainment of the architecture products either internally, or with persistent contractor support. Ideally, contractor support can effectively be used to initiate enterprise architecture development when conducted in conjunction with permanent party personnel who can exercise continuing maintenance of the EA. Many architecture projects are overstaffed at the onset if critical architectural work needs to be expedited, which may indicate that an organization is not investing sufficient time in the architecture analysis and development.[18] DoDAF version 1.5 warns that the architectural views are not important; the key issue is the integrity of the data used to produce the views.

Communication

The nature of enterprise architecture is to capitalize on horizontal integration; standardizing processes and eliminating redundancies; which leads to another possible pitfall: communication. Some organizations charged with development of LogEA artifacts display a lack of communication across organizations, and cross flow of information among geographically separated organizations is an ever present issue. Without adequate communication between eLog-21 initiatives, systems that need to be integrated and interoperable may not achieve the overall goal. Some of the initiatives are so expansive that several large architecture teams are employed in disparate locations for artifact development. Significant differences in process understanding and even architecture styles are evident in many artifacts submitted for approval. If processes cannot be standardized within a single organization, it is easy to see how communicating vital information between agencies would be difficult. This problem of standardization is apparent throughout all levels of LogEA.

Standardization

Though all architecture products are measured by their adherence to the DoDAF by way of the LogEA Compliance Plan, there is no prescribed methodology or software package for architecture modeling. Though different product suites were used to develop enterprise architecture in each of the case studies, there was standardization of software and training for each project. Software integration and interoperability is a key element of enterprise architecture, so it would seem appropriate to ensure the same interoperability for all architecture developments. This is problematic as artifacts are approved and certified. Original products cannot be maintained in a central repository due to the lack of standardization among software, and it is a point of discussion how maintenance and archiving of the LogEA will be accomplished.

Conclusion

It has been said that the architecture of an enterprise exists, whether it is explicitly developed or not. By virtue of process, system, and technical make up, architecture is inherent in all organizations, even if it is not formally defined. The discipline of enterprise architecting allows the capitalization of the potential effectiveness and efficiency of an organization, while minimizing cost. A well established EA also guides acquisition of new technologies and facilitates change management and transformation. The institution of enterprise architecture has emerged as common practice within commercial industry and is mandated now for all federal enterprises. Though enterprise architecture is not a topic requiring expertise for every member of an organization, it is valuable to have a fundamental understanding of what it is and why it is being used. This article was intended to provide the reader with a fundamental understanding of the background, practices, and possible complications associated with enterprise architecture. Though it is a relatively new mandate within the Air Force, EA will offer substantial benefits if properly implemented throughout the enterprise.

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Thinking About Logistics Analysis

Introduction

The current focus in logistics analysis relies heavily on the use of averages. There are instances where predictive modeling is used; however, data requirements for predictive modeling to be accurate are often not being met by the logistics community.

Predictive modeling, probability management, and stochastics provide a backbone for data analysis requirements in tomorrow's Air Force logistics community. In order for these techniques to provide real benefit, data integrity must be maintained. The implementation of an Enterprise Resource Planning (ERP) system in the logistics enterprise allows for an integrated common database, alleviating errors and wait time in transferring data between logistics systems. In the logistics community of the Air Force, the ERP system, along with the demand planning and repair scheduling programs is called the Expeditionary Combat Support System (ECSS). As the logistics community moves to install ECSS, new analysis techniques can be used to more accurately predict future requirements for manpower, transportation, supply, maintenance, and other areas of agile combat support throughout the logistics enterprise.

Current State of Logistics Analysis

Throughout the logistics world, the Air Force uses averages in metrics and decision support. Examples include determining stock purchases by averaging pipeline transportation and repair times in conjunction with average demands, determining schedules of transportation assets based on average required capacity, and buying jet fuel at an average rate per year. The dangers associated with averages can be put into categories:[1]

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A shift in information management that captures the statistical relationships of uncertainties is essential to management of risk, real options, and enterprise level logistics.

- **The Family with 1.5 Children**. The average data does not take into consideration the actual population. When transportation times for items are entered into Air Force computer systems, such as the D200 Requirements Management System, average times are used. These averages do not often capture the reality of transportation times, as illustrated by the fact that they are used less than 35 percent of the time. These transportation times are used to determine pipeline length, and subsequently, purchase requirements. The danger of errors and poor data management results in significant back orders.[2]
- **Ignoring Restrictions.** When preparing for average demand, a certain amount of capacity is allocated to meet that demand. If demand exceeds capacity, demand is limited by capacity. If capacity exceeds demand, overcapacity exists. Using the average required capacity to schedule transportation assets for Air Mobility Command to be used by United States Transportation Command presents this danger. If the demand for assets is lower than the capacity, assets will be underutilized. Conversely, if demand is higher than the required capacity, throughput will be limited by the capacity of transportation assets. This problem becomes more evident when combining the weight, cube, and palletization of assets.[3]
- **Ignoring Optionality.** On a commodity with volatile prices and a constant demand, stockpiling during periods of low cost can offset the demand during periods of high cost. Using the projected average price on fuel, every fiscal year the fuel price for the Department of Defense, including jet fuel, is set as a fixed rate. This is a very different strategy than the established best practices in the airline industry. Southwest Airlines, the only profitable United States based airline, uses a process called fuel hedging. Hedging is the act of stockpiling fuel at periods of low cost, and not purchasing at periods of high cost. This act capitalizes on the volatility of fuel prices, and saves Southwest more than $150M per quarter.[4]

Additional categories, illustrated by notional examples, include:

- **Why Everything Is Behind Schedule**. Delivery of 10 parts is pending. The delivery time for one part is uncertain and independent, but known to average 1 week with a 50 percent chance of being over or under. It is tempting to estimate delivery as 1 week, but for that to happen, each part would have to arrive at or below the average delivery time. This is the same probability as flipping 10 sequential heads on a fair coin.
- **The Egg Basket**. Consider 10 mission critical parts being transported on the same convoy and the alternate case of one mission critical part on each of ten convoys. If there is a one-in-ten chance of losing any convoy, then either strategy results in an average of nine parts reaching their destination. However, the first strategy has a one-in-ten chance of losing every part, whereas the second strategy has a one-in-10 billion chance of losing all of the parts.
- **The Double Whammy**. Consider an inventory of perishable items. Here there is a spoilage cost associated with having too many of the items. There is also a back order cost associated with having too few of the items. The cost associated

with the average demand is zero, since items are stocked to meet average demand. However, on average there will be a cost associated with stocking items, as forecasts are very rarely identical to demands.

These examples illustrate the dangers associated with using averages. Use of averages is widespread in the Air Force and can limit the ability of logisticians to make informed decisions.

Future State of Logistics Analysis

Logistics in the modern era is driven by uncertainties that create a significant number of interdependent risks. If the underlying statistical relationships of the uncertainties driving these risks are captured during the planning process, they can be exploited to find the optimal risk-based tradeoff for increased logistics performance. A shift in information management that captures the statistical relationships of uncertainties is essential to management of risk, real options, and enterprise level logistics.[5]

As is seen in several programs throughout the Air Force, most notably the Logistics Composite Model (LCOM), the use of predictive management in making manpower decisions is essential to future operations. LCOM is a Monte Carlo simulation that uses simulated flying schedules to predict maintenance requirements. LCOM uses historical data, including the mean time between failures and the mean time to repair, to determine how many personnel and of what levels are required in each shop to handle the typical work flow. Given available data in current maintenance systems, LCOM is the best tool to predict this manpower requirement.[6] If data becomes more accurate and more available in the future, then all Air Force logistics functions can take advantage of predictive modeling and simulation to make manpower decisions. In the future state of logistics, additional factors in predictive management such as aircraft availability, spares packaging, spares leveling, and manpower decisions throughout logistics will need to be considered as the Air Force has to perform its mission more effectively with fewer people.

A mature ERP system, however, can provide the logistics community with the data required to obtain underlying data trends required to perform predictive analysis.

The adequacy of a simulation is limited by the availability of data and modeling of tradeoffs between variables. As is the case in many simulation applications, the oversimplification of data into averages inadequately accounts for uncertainty and risk. Often values of input such as time, manpower, and failure rates are simplified into mean, average, or *base case* values which serve as inputs and outputs from the model. The previous example of mean times taken from the D200 Requirements Determination System to simulate pipeline times in readiness-based leveling (RBL) computations[7] illustrates this point. The current data accuracy, availability, and timeline does not support predictive analysis and simulation to aid logistics decisionmaking. A mature ERP system, however, can provide the logistics community with the data required to obtain underlying data trends required to perform predictive analysis.

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The implementation of an ERP system within the Air Force logistics enterprise will allow for an integrated common database. This instantaneous availability of data allows for new tools to be more readily applied to data analysis. Instead of using averages, which have been shown to oversimplify variability when dealing with uncertain behavior, logisticians can use probability management to predict some uncertain behaviors.

ERP Defined

Gartner defines ERP as "a set of applications software that brings manufacturing, financials, distribution, and other business functions into balance."[8] In other words, an ERP is one system used to manage all operations within a business enterprise. ERP systems provide an organization with a database backbone. All data is fed into the backbone and updated to the rest of the enterprise in real time. With organizational systems' barriers removed, business processes can focus on reducing the time wasted on handoffs between functional areas (the most common point of waste in most companies).[9] In addition, most ERP systems are built and installed with industry-wide best practices for data management.[10] This does not necessarily remove a competitive advantage that a company has; it does allow companies to model their enterprise processes around an industry proven process.

ERP systems have both risks and benefits associated with them. Some of the benefits are common data, real-time information and asset visibility, and enablement of business process reengineering. Some of the risks associated with ERP systems (specifically in their implementation) are that gaps can occur between the current state and future state capabilities, implementations frequently run over budget and behind schedule, and very little real cost benefits will be seen without major process modifications supporting the changing business data structure.[11]

In order for the Air Force to meet the goals set by logistics enterprise architecture (LogEA) initiatives—20 percent increase in aircraft availability and 10 percent cost reduction[12]—and manpower cuts in the Program Budget Decision 720,[13] major change is needed in both process management and system functionality. The legacy computer systems in the Air Force logistics enterprise are not capable of meeting the faster-paced communication capabilities required by today's suppliers and customers in the end-to-end supply chain of Air Force logistics.[14] Much like the commercial world is driven by outside pressures to a new information technology (IT) system that can handle the increased communication and flexibility requirements of their suppliers and customers, the Air Force logistics enterprise must change to meet the increasing demand on our systems. ERP will be the Air Force's tool of the future to facilitate these business changes.[15]

The implementation of an ERP system within the Air Force logistics enterprise will allow for an integrated common database. This instantaneous availability of data allows for new tools to be more readily applied to data analysis. Instead of using averages, which have been shown to oversimplify variability when dealing with uncertain behavior, logisticians can use probability management to predict some uncertain behaviors.

Examples of Probability Management

Shell Exploration and Production (SEP) illustrates the use of probability management. In order to meet the demands of global uncertainties, SEP engaged in

reorganizing into a global operating model engaged in the upstream activities of acquiring, exploiting, developing and producing oil and gas.[16] This involved the combining of local and regional activities into a single, centralized business organization managing a large portfolio of venture opportunities, with data management at its core.[17]

Shell typically used a bottom-up assembly of exploration ventures into a business planning function. That is to say, each regional business section of Shell would develop and rank possible business ventures based on perceived risks and rewards. Shell made a transition to a top-down capital allocation approach that involved the use of stochastics. Shell developed a stochastic library involving factors such as hydrocarbon volumes, drilling and developmental costs, volumetric distributions, and economic values of exploration.[18] SEP insured the libraries were simple to understand and easy to apply but detailed enough to be credible. Shell included individual libraries for global scenarios so that each venture could be assessed on the impact to the global environment. What Shell created was not a simple risk and reward tradeoff curve—instead the potential tradeoffs between several pairs of metrics could be seen. Management at Shell could open the graphic user interface and select or deselect investment projects with a click of the mouse. This action created a profile, driven through Excel formulas, where repetitions were driven by precalculated Monte-Carlo trials within the stochastic library. Because the simulations were not taking place at the mouse click, existing trials were being used, the statistical properties of the profile were immediately apparent. [19]

With this approach, management could now see various investment levels through group interactions within the model. The reward was that managers now were forced to focus on big picture issues, and the impact of their organization within the business enterprise.

The Shell approach is applicable for Air Force logistics. The current bottom-up approach involving the manipulation of wing level metrics can become a top-down assessment of how each wing can benefit or hurt the Air Force logistics enterprise. In order to accomplish this top-down approach, data integrity and availability must be ensured at the highest levels of planning.

"Chronic 'good enough' incremental investments deteriorate long-term market position."

Another example of an ERP implementation is Sloan Valve. Sloan Valve is a small company that is approximately 100 years old and has always remained privately owned. They manufacture bathroom equipment; in fact, they have 80 percent of the market on hands free bathroom fixtures in America. In 1998, Sloan Valve installed an ERP system but saw little initial return on investment from their system. They frequently undertook incremental investments that attempted to refine processes, what the Air Force calls continuous improvement. As Dr Michael Hammer describes this phenomenon of low return on investment, "chronic 'good enough' incremental investments deteriorate long-term market position." Seeing a need for dramatic change, Sloan used the ERP system as a catalyst to develop end-to-end business processes that focused on what, where, and when work needed to be done.

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Predictive modeling, probability management, and stochastics can be used in tandem to meet logistics analysis and data analysis needs of tomorrow's Air Force logistics community. Data requirements for this type of analysis are not being met by current logistics systems.

Another successful ERP implementation is Welch's. Evolving customer needs dictated a need to change, and management needed better visibility through the order management process. Welch's committed to an ERP system which involved business process reengineering at its core. The benefits they have seen from their ERP system include a decrease in total customer deductions for mistaken orders and missed contract deadlines. Deductions as a percentage of net sales dropped from 1.2 to 0.5 percent in a 2-year period. In addition, their days on hand of inventory and cash dropped from 25 days to less than three days, reducing the financial and logistics footprint of their business enterprise.[23]

A common factor in the implementation strategies of Sloan Valve and Welch's involved changing their business processes to take advantage of data availability in ERP systems. These changes impact the throughput and efficiency throughout the business enterprise. The Air Force can expect similar, drastic changes to their business processes as ECSS is implemented. While dealing with the uncertainties of changes facing Air Force logistics, predictive analysis will provide the decisionmakers with the information needed to understand the tradeoffs of decisions. Predictive analysis allows for modeling and stochastic analysis of decisions before they are made, providing a decision support tool for agile combat support.

Conclusion

In order to meet the uncertainty of real world logistics situations, a predictive modeling technique for logistics analysis is required in the Air Force. Predictive modeling, probability management, and stochastics can be used in tandem to meet logistics analysis and data analysis needs of tomorrow's Air Force logistics community. Data requirements for this type of analysis are not being met by current logistics systems. The implementation of ECSS, the Air Force's ERP system, and the integrated database feature associated with the system, will meet the data requirements of this future state of logistics analysis.

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