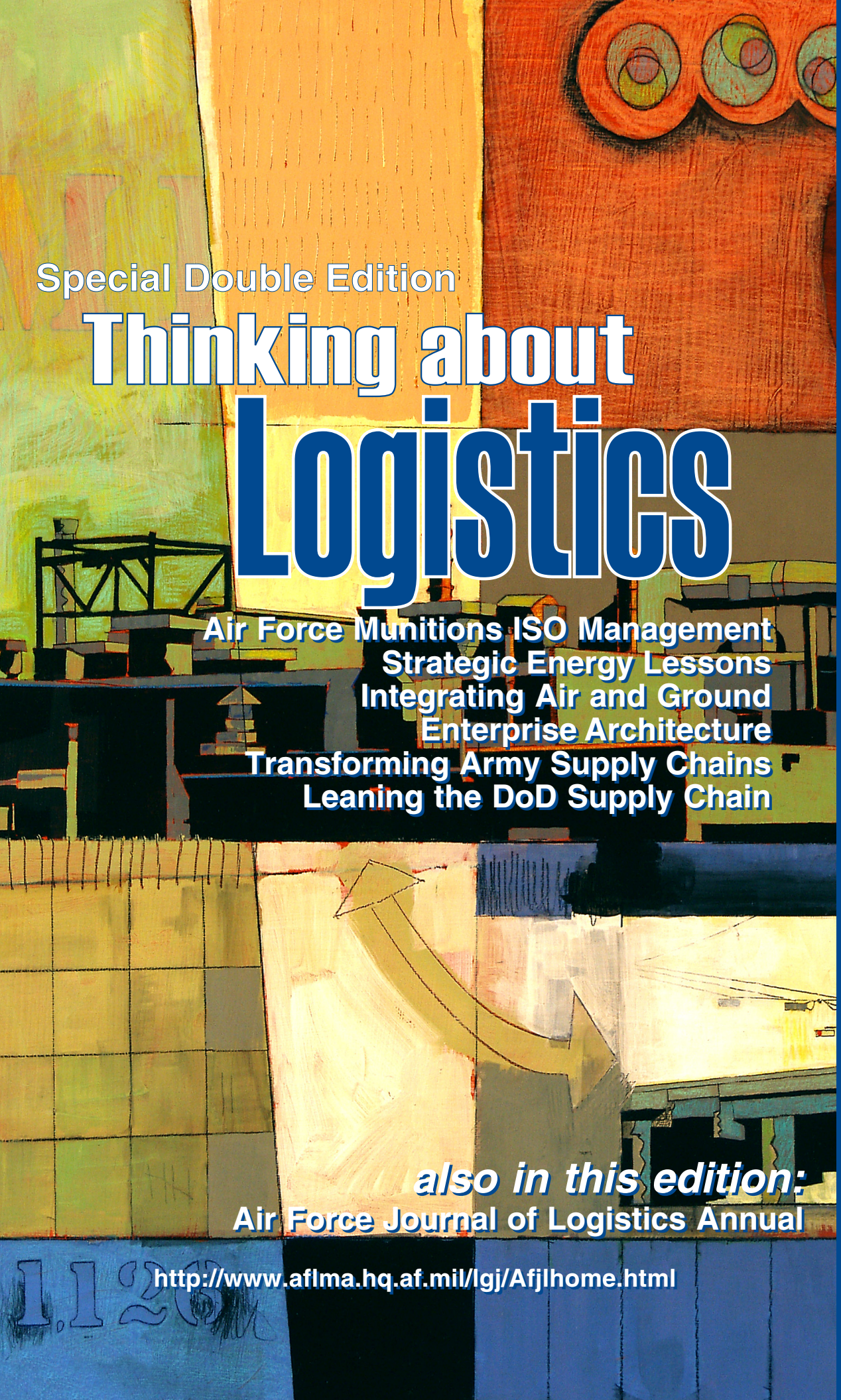

Special Double Edition

Thinking about Logistics

Air Force Munitions ISO Management
Strategic Energy Lessons
Integrating Air and Ground
Enterprise Architecture
Transforming Army Supply Chains
Leaning the DoD Supply Chain

also in this edition:
Air Force Journal of Logistics Annual

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AIR FORCE JOURNAL of LOGISTICS

Volume XXXII, Number 4 and Journal Annual, Volume XXXIII, Number 1

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SPECIAL IN THIS EDITION

89 **Journal of Logistics Annual**

General Norton A. Schwartz
Air Force Chief of Staff

Deputy Chief of Staff, Installations, Logistics, and Mission Support

Roger D. Golden, DPA
Director
Air Force Logistics Management Agency

Editor-in-Chief
James C. Rainey
Air Force Logistics Management Agency

Editor
Cynthia J. Young
Air Force Logistics Management Agency

Contributing Editor
Roger D. Golden, DPA
Air Force Logistics Management Agency

Journal Telephone Numbers - DSN 596-2335/2357 or Commercial (334) 416-2335/2357

Cover artwork for this edition of the Journal was graciously supplied by Stephen Dickerson. Mr Dickerson is a full time visual artist living in Houston, Texas. His paintings balance an interest in the abstract elements of shape, line, and color with the narrative possibilities of recognizable objects. He shows his work regularly in galleries, shows and exhibitions.

The cover art, *Lateral Movement*, is a painting about the numerous indirect movements required to complete a road trip from Houston to Chicago. The number in the lower left hand corner (1,126) is the distance from a certain industrial site in Chicago to exit 743 in west Houston (acrylic and pencil 24 x 24 inches).

The *Air Force Journal of Logistics* (*AFJL*), published quarterly, is the professional logistics publication of the United States Air Force. It provides an open forum for presenting research, innovative thinking, and ideas and issues of concern to the entire Air Force logistics community. It is a nondirective publication. The views and opinions expressed in the *Journal* are those of the author and do not necessarily represent the established policy of the Department of Defense, Department of the Air Force, the Air Force Logistics Management Agency, or the organization where the author works.

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Unsolicited manuscripts are welcome from any source (civilian or military). They should be from 1,500 to 5,500 words. The preferred method of submission is via electronic mail (e-mail) to: **editor-AFJL@maxwell.af.mil**. Manuscripts can also be submitted in hard copy. They should be addressed to the *Air Force Journal of Logistics*, 501 Ward Street, Maxwell AFB, Gunter Annex AL 36114-3236. If hard copy is sent, a zip disk or compact disk containing an electronic version of the manuscript should accompany it. Regardless of the method of submission, the basic manuscript should be in Microsoft Word or WordPerfect format, and all supporting tables, figures, graphs, or graphics must be provided in separate files (preferably created in Microsoft Office® products; if Microsoft Excel is used to create any of the charts or figures, the original Excel file must be supplied). They should not be embedded in the manuscript. All submissions will be edited in accordance with the AFJL submission guidelines.

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Special Feature

Oil is the lifeblood of war in our times. Without it a nation cannot fight. It is the basic munition. There is nothing else the deprivation of which would have so damaging an effect upon a country's prospect of achieving victory. The loss of it would mean, indeed, the certainty of defeat. However great the reserve of manpower and machine-power, however ample the armaments that have been amassed, a nation could not hope for victory if it lacked the oil-power without which its men, its machines, and armaments would be immobilized and powerless.

—James Molony Spaight, C.B., C.B.E., *The War of Oil*

Thinking about logistics

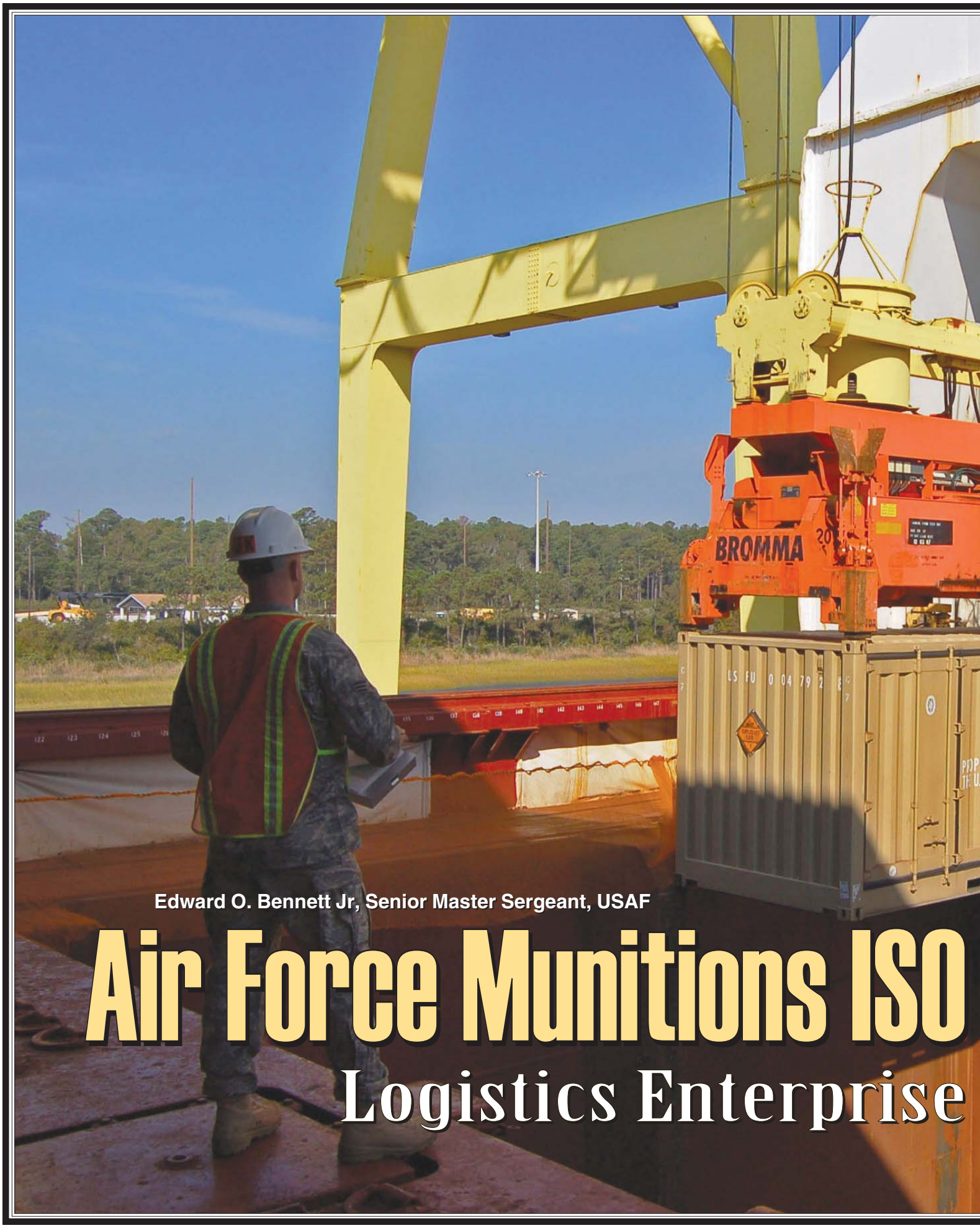
Air Force Munitions ISO Management: Logistics Enterprise for Containers
Strategic Energy Lessons: A Historical Perspective Applied to America's Source Issues
Integrating Air and Ground: Joint Theater Distribution System

This speial double edition of the Journal presents three featured articles: "Air Force Munitions ISO Management: Logistics Enterprise for Containers," "Strategic Energy Lessons: A Historical Perspective Applied to America's Source Issues," and "Integrating Air and Ground: Joint Theater Distribution System."

In "Air Force Munitions ISO Management: Logistics Enterprise for Containers," the author presents the results of an Air Force Logistics Management Agency (AFLMA) analysis comparing the use of the common commercial ISO (International Organization for Standardization) pool to total ownership of ISO containers to meet Air Force contingency munitions needs. This article documents the relevant background information, problem, objectives, methodology, research, and findings associated with this effort.

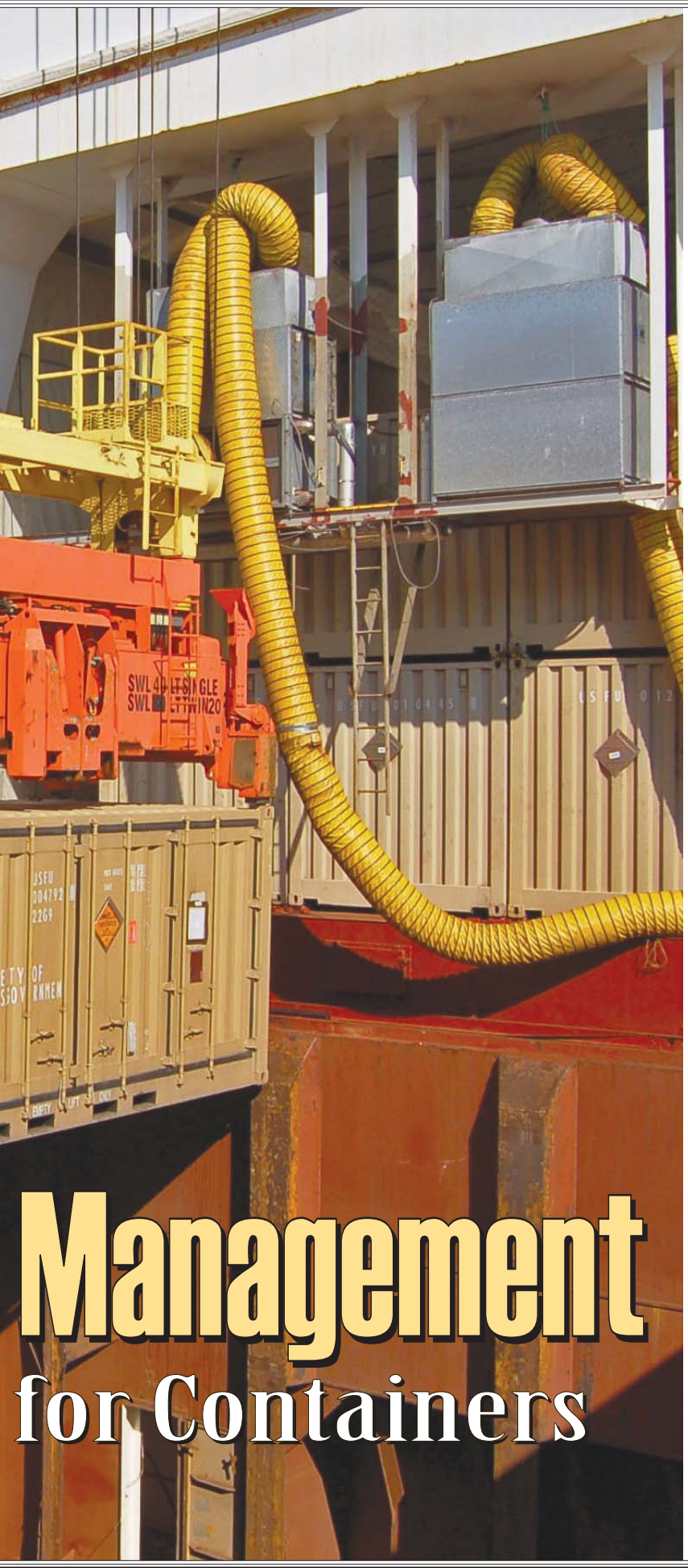
The second featured article investigates a past coal-to-liquids program (German efforts during WWII) to determine whether there are strategic lessons for the United States that can be applied to today's energy situation, seen particularly from the perspective of national security.

In the concluding article the authors make the case that a single command structure responsible for the movement control of the theater could better utilize available assets to meet mission requirements by selecting the mode that would be most effective for the mission.



Edward O. Bennett Jr, Senior Master Sergeant, USAF

Air Force Munitions ISO Logistics Enterprise



Management 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]

Special Feature

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 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

Article Highlights

Rapid response swing stocks are used to help fill the differences between the theater's minimum munitions stockpile requirements and on-hand stocks.

Currently, the Air Force has ownership of 5,428, 20-foot ISO containers to support Afloat Prepositioned Fleet (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 Military Ocean Terminal Sunny Point as spares. 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.

Annual cost of repair for the current balance of 5,428 is approximately $52K annually. 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 the Army Intermodal Distribution Platform Management Office (AIDPMO) to be utilized by any Department of Defense (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.

AIDPMO has agreed to accept responsibility of all excess containers turned over to their agency to include all transportation costs. 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. With the additional 3,197 ISO containers turned in by APF

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.
- 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 to DoD stockpile (controlled by AIDPMO), leasing containers for munitions movements would be virtually eliminated.

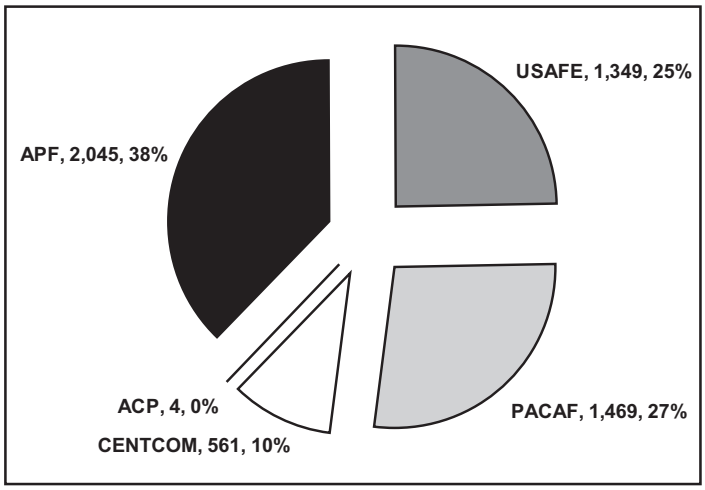


Figure 1. ISO Distribution

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. 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.

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 provide responsive and effective ACS by allowing the flexibility total ownership provides and cost avoidance of approximately $16M.

Article Highlights

Article Acronyms

ACS – Agile Combat Support
AFLMA – Air Force Logistics Management Agency
AFMC – Air Force Materiel Command
AIDPMO – Army Intermodal Distribution Platform Management Office
AMST – Agile Munitions Support Tool
APF – Afloat Prepositioned Fleet
CENTCOM – Central Command
CCDR – Combatant Commander
DoD – Department of Defense
FY – Fiscal Year
ISO – International Organization for Standardization
MAJCOM – Major Command
MOTSU – Military Ocean Terminal Sunny Point
MV – Motor Vessel
PACAF – Pacific Air Forces
PEC – Program Element Code
US – United States
USAFE – United States Air Forces in Europe
WRM – War Reserve Materiel

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).

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

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.

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 element code (PEC) 28030 expense (PEC 55396F for Air Force Reserve Command).[13] The cost to manage and

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

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.

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 provide responsive and effective ACS by allowing the flexibility total ownership provides and cost avoidance of approximately $16M.

Notes

1. *FY2008–2019,* US Air Force Directorate of Installations, Logistics, and Mission Support, *Afloat Prepositioned Fleet Strategic Overview,* (2008).
2. *Ibid.*
3. *International Standards for Business, Government and Society*, [Online] Available: International Organization for Standardization: http://www.iso.org/iso/about.htm, August 2008.
4. *Afloat Prepositioned Fleet Strategic Overview.*
5. 784th Combat Sustainment Group, 505th Combat Sustainment Squadron, Readiness Division, *Afloat Prepositioned Fleet Battle book*, (2008).
6. USAF Combat Ammunitions System and Agile Munitions Support Tool, *CAS and AMST.*
7. R. O'Conner, (July–August 2008), 2d Lt, USAF, AFMC 505/CBSS/GBLA, OIC APF Operations, (E. Bennett, Interviewer).
8 USAF Combat Ammunitions System and Agile Munitions Support Tool.
9 R. O'Conner.
10. *Ibid.*
11. S. Gorba, (July–August 2008), Chief, Army Intermodal and Distribution Platform Management Office, (E. Bennett, Interviewer).
12. D. Rumford, (July–August 2008), Logistics Analyst, III-SAIC, AIDPMO, (E. Bennett, Interviewer).
13. AFI21-201, *Conventional Munitions Maintenance Management,* 23 Nov 2007.

Senior Master Sergeant Edward O. Bennett Jr*, is currently the Weapons Systems Superintendent for the Air Force Logistics Management Agency at Maxwell AFB, Gunter Annex, Alabama. Additionally, he occupies a key position in support of the Chief of Staff of the Air Force Title X and Joint wargames and is one of the Air Force Logistics Management Agency's Expeditionary Combat Support System focal points.*

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Special Feature

Extending hope and opportunity depends on a stable supply of energy that keeps America's economy running and America's environment clean. For too long our nation has been dependent on foreign oil. And this dependence leaves us more vulnerable to hostile regimes and to terrorists—who could cause huge disruptions of oil shipments, and raise the price of oil, and do great harm to our economy.

—President George W. Bush, State of the Union Address, January 23, 2007[1]

Introduction

Energy is arguably the greatest national security issue for the United States (US). By late 2007, oil broke the $100 a barrel mark. Climate change is being blamed on ever increasing levels of energy usage, resulting in the inevitable conclusion that American national security strategy is being affected by long-term energy considerations.[2] Energy was a major section of the President's State of the Union speech in January 2007, where he outlined a proposal to reduce gasoline usage 20 percent in the next 10 years (*Twenty in Ten*).[3] This position was reemphasized in the 2008 State of the Union. According to the US Department of Energy's Annual Energy Outlook for 2008, oil prices are high enough to trigger the initiation of alternative energy processes in the $30 to $60 range (2006 dollars). These

Strategic Energy Lessons

A Historical Perspective Applied to America's Oil Source Issues

Michael E. Puckett, USAF

Article Highlights

Instead of debating what the parameters of a comprehensive energy security strategy should be, considerable time has been spent by the American government discussing the tactical details of industrial processes.

This article will focus primarily on the issues surrounding replacing imported crude oil as the strategic imperative. Alternative or synthetic fuel manufacturing is not a novel approach. The technical work started nearly a century ago in Germany was advanced considerably in the period of 1924 to 1945.

The United States' own shortages in domestic oil sources indicate sufficient similarity of circumstances to warrant seriously considering the lessons to be learned from the German experience over 60 years ago. They are simple, but still viable in today's world.

- Recognize and admit you have a problem
- Commit to a course of action
- Support the existing developmental and technology efforts
- Emphasize conservation
- Establish a strategic framework focused on successful results

When a comparison is made to the actions taken to date it indicated that America may have admitted it had a problem over 30 years ago, but has been very slow to commit to a long-term course of action to address the problem. The extensive current activity around biofuels is foundational, but the nation's resources have not been sufficiently committed. Congressional funding does not appear to be robust enough to encourage the capital investment needed to ensure long-term success. The current administration's efforts and those of Congress are a good start, but a start only. America imports nearly 66 percent of its petroleum needs every day. Biofuels will replace about 30 percent of current US petroleum consumption. The remaining 36 percent will have to be addressed as well—renewable sources may be preferred, but if those renewable sources are incapable of freeing the US from its imported oil include oil sands, ultra-heavy oils, gas-to-liquids, and coal-to-liquids (CTL).[4] This article investigates a past CTL program to determine whether there are strategic lessons for the United States that can be applied to today's energy situation, seen particularly from the perspective of national security.

Given energy's ability to touch everybody and everything in modern life, there are a myriad of topics to consider in the energy realm—social, economic, strategic, ecological, and political. Some are very personal, such as when people are told they may not be able to drive their favorite vehicle, or the prospect of a new energy production plant being considered for construction in the neighborhood. Energy issues also affect the ability of the state to project power in order to protect and defend its citizens or influence its relationships within the global community.

Instead of debating what the parameters of a comprehensive energy security strategy should be, considerable time has been spent by the American government discussing the tactical details of industrial processes. Discussions today are reminiscent of the Japanese debate regarding the decision to attack Pearl Harbor—allowing the argument itself to divert from the central issue of "what should be done" to "how it should be done."[5] The debate approach taken by America has allowed for recurring politicized arguments covering the same issues such as the oil peak question, greenhouse gas (CO_2) emissions, climate impacts, and economic impacts to local constituents.

Meanwhile, the American and world economy continues to be affected by the surging price of oil. Energy prices have a direct impact on the consumer price index (CPI), and are a key cause of inflation. Long-term and sustained price increases impact other commodity prices and further impact the economy through a lagging effect on CPI inflation. Historically, the pressures of energy prices on aggregate prices in the economy have created problems for the economy as a whole, occasionally driving a downward adjustment to expected growth projections. Continued economic recession is a distinct possibility in the current economic climate due in part to the cost of oil.[6] According to the Energy Information Agency, a $25 per barrel increase in the price of crude oil results in a 1 percent drop in American Gross Domestic Product. The trade imbalance provides oil supplying countries potential leverage over US capital markets. Energy dependency influences foreign affairs and reduces American freedom of action; and it can empower countries such as Iran and Venezuela to pursue policies hostile to the US.[7] This dependency will be a continuing issue as the energy demands of China, India, and the rapidly industrializing third world continue to accelerate.

US oil imports started exceeding oil production in the 1990s (see Figure 1). A General Accountability Office (GAO) report in February 2007 yet again articulated a policy perspective repeated from the Nixon administration on imports that in some respects dates back to Franklin Delano Roosevelt's administration—the requirement for a cohesive approach to meeting the oil needs of the United States.

With respect to the peak oil issue, the report stated the following:

> While the consequences of a peak would be felt globally, the United States, as the largest consumer of oil and one of the nations most heavily dependent on oil for transportation, may be particularly vulnerable. Therefore, to better prepare the United States for a peak and decline in oil production, we are recommending that the Secretary

of Energy take the lead, in coordination with other relevant federal agencies, to establish a peak oil strategy. Such a strategy should include efforts to reduce uncertainty about the timing of a peak in oil production and provide timely advice to Congress about cost-effective measures to mitigate the potential consequences of a peak. In commenting on a draft of the report, the Departments of Energy and the Interior generally agreed with the report and recommendations.[9]

From a strategic perspective it is irrelevant whether the oil peak is 1 or 10 years away. It is prudent for the US as the biggest global consumer to develop a policy to account for the issues that can be anticipated on the other side of peak oil, whenever it might come. Indeed one can take from the failure to find *significant* oil fields since the 1960s, combined with drastically increased demand in Asia, that the peak is now an academic point and strategically irrelevant in terms of justification for policy planning action.

This article will focus primarily on the issues surrounding replacing imported crude oil as the strategic imperative. Alternative or synthetic fuel manufacturing is not a novel approach. The technical work started nearly a century ago in Germany was advanced considerably in the period of 1924 to 1945. It was strongly considered by the Allies both before and during the Second World War and actually used by the British at a Billingham plant to produce 100,000 tons of high quality synthetic gasoline a year for the Royal Air Force.[10] Much can be learned from the German experience which should be investigated when discussing any synthetic fuel approach to changing the source of US energy supplies.

Put to one side the character of the Nazi regime and its atrocities. There is a great deal to be learned from some of the strategic decisions and the scientific or engineering accomplishments of German synthetic fuel programs. This study will therefore identify the German causes for action, examine the impact that action had on Germany's ability to pursue its national goals and objectives, and outline several strategic lessons that can be applied to the current energy situation. It will then look at American policy efforts over the past few decades and compare those efforts to the lessons and observations regarding their effectiveness in meeting the needs of US energy policy. The huge difference in the political nature of the national system of wartime Germany and that of modern US government urge caution in such an analysis. This article seeks to learn from the German technical capabilities and the role of the state in planning and pursuing energy policy for strategic purposes.

Assumptions

The following assumptions are used in this article:

- Access to oil is the number 1 critical, strategic, and economic imperative of the United States.
- The United States is not self-sufficient in oil. Coal and nuclear fuel reserves exist for US use into the foreseeable future.
- Technical and ecological concerns in coal and nuclear power generation can be overcome with emerging technologies and processes.
- The worldwide oil peak is not an accurate trigger for action. The peak discussion is almost immaterial at this point. Oil reserve data is extremely questionable.[11] Worldwide demand is ballooning due to China, India, and the developing third world.[12] Global oil demand is accelerating (see Figure 2).

Article Highlights

dependency, other methods are clearly available and in most cases commercially viable with today's volatile oil prices. Also remaining are residential and commercial power issues and whether this will be addressed by clean-coal technology or by nuclear power stations.

Timing is also an issue. The extended time frame being used with the current efforts, especially conservation, may only cover future growth in national energy demands. This means current plans would only preclude additional large crude oil import requirements—not necessarily drive import reductions in the near term. Building a new infrastructure for biomass based fuels may take some time, but conservation efforts in the transportation sector would be of greater immediate benefit. New corporate average fuel economy standards were overdue, but are not aggressive enough to be of any near-term assistance to alleviating oil import-imbalance-driven inflation on America's economy or improving national security.

Finally, improving current processes, exploring other existing technologies, and developing new ones should be continued and nurtured. Biomass fuels need cheaper enzymes to help break down the cellulose for processing. Nanotechnology might be used to develop artificial enzymatic biomass factory processes to manufacture ethanol or other petroleum products. Some commercial use could be found for all the carbon dioxide to be produced by clean-coal technology. Other energy renewables such as wind, tidal, and solar show potential as the technology evolves.

Article Acronyms

CAFE – Corporate Average Fuel Economy
CO_2 – Carbon Dioxide
CPI – Consumer Price Index
CTL – Coal-to-Liquids
FT – Fischer Tropsch
GAO – Government Accountability Office
GWOT – Global War on Terror
H.R. – House Resolution
MYPP – Multi-Year Program Plan
R&D – Research and Development
STL – Solid-to-Liquid
US – United States

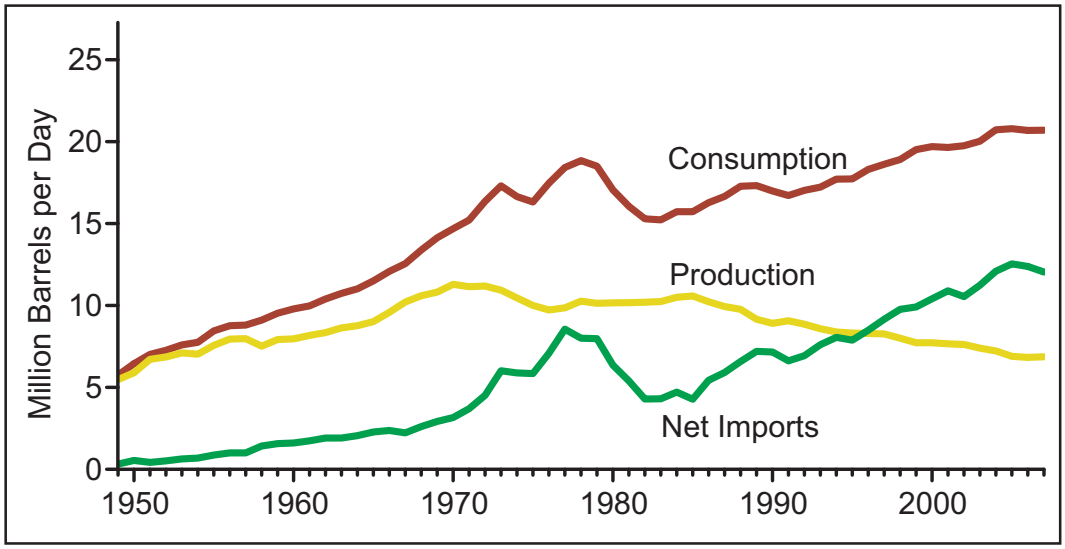

Figure 1. US Consumption, Production, and Imports of Oil, 1949-2005[8]

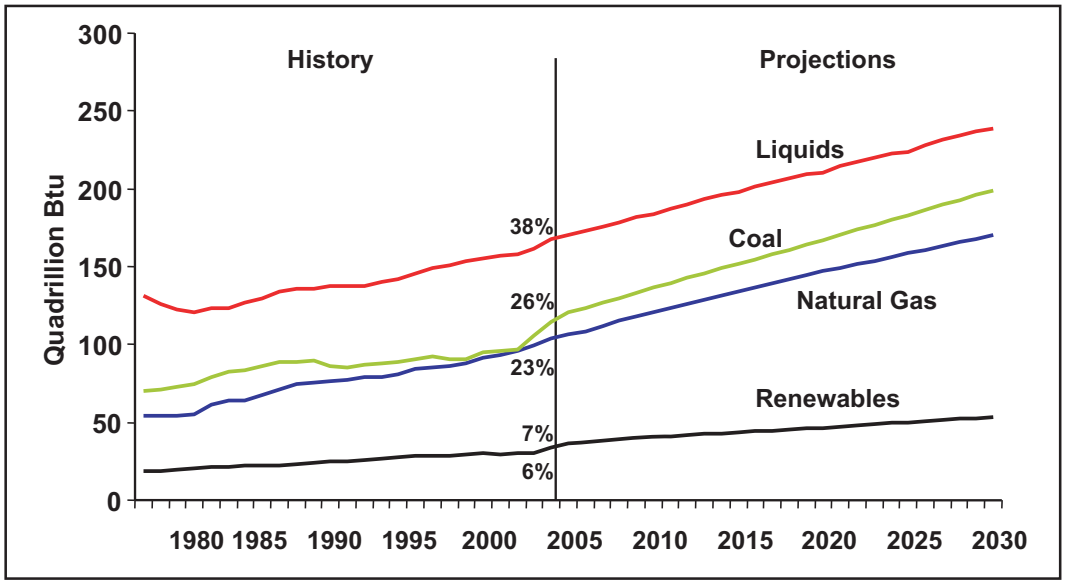

Figure 2. World Marketed Energy Fuel Use by Fuel Type 1980-2030[13]

- Global warming and climate change is a real issue.
- Solid-to-liquid (STL) alternatives must be part of the energy supply solution. The technology is mature enough to be used as a midterm solution and then retained as part of a diverse energy policy. Continuity of supply is vital. STL does come at an environmental cost from a CO_2 output perspective which has to be addressed to achieve viability. An attempt at addressing this is in the recently signed *Energy Independence and Security Act of 2007*[14] and other pending legislation.[15]
- Oil alternatives, such as shale oil/sand show promise, but they are beyond the scope of this investigation.
- Renewable energy is a better all-around, long-term solution. The technology and manufacturing processes are quickly evolving to both manufacture and utilize the resultant products in vehicles. At worst it is environmentally neutral with regard to atmospheric carbon emissions—essentially recycling existing carbon.
- Time terminology used: near-term, 3 to 5 years; midterm, 5 to 10 years; long-term, greater than 10 years.

The German Historical Perspective

In the early years of the twentieth century, German scientists and engineers recognized that Germany's energy requirements were changing for two reasons: 1. Germany was becoming increasingly dependent on internal combustion engines and 2. Germany's continuing industrialization and urbanization magnified the shortcomings of coal as an energy source. Petroleum was clearly the fuel of the future and Germany needed to ensure that it was never without it.[16] The breakthrough came in 1914 with the development of a continuous hydrogenization of coal process by Frederich Bergius. The start of World War I revealed Germany's critical need for petroleum as nearly all oil was imported. Bergius did attempt to establish a commercial hydrogenization facility at Rheinau during the period of 1915 to 1918, but technical start-up issues, along with Germany obtaining access to the Romanian oil fields resulted in minimizing the importance of converting coal to petroleum. The first hydrogenization plant was not completed until 1924 following research and development by Bergius and other German scientists.[17] Frederick Bergius and Carl Bosch received the Nobel Prize in 1931 for their contributions to high-pressure methods in chemistry—a key methodology in hydrogenization's success.[18]

Research and development did not stop with the success of Bergius' method. During the 1920s and 1930s, another CTL petroleum process was developed in Germany by Franz Fischer and Hans Tropsch (FT)—the indirect synthesis of petroleum from carbon monoxide and hydrogen, known as the FT method. The two methods were not in direct competition, as coal hydrogenization was more advanced and better suited to high quality aviation and motor fuel, while the FT process gave high quality diesel, lubricating oil, waxes, and lower quality motor fuel.[19]

Following the First World War in the early 1930s, Germany was struggling with rebuilding its economy, suffering from the worldwide depression, and continued looking for alternatives that either limited or eliminated their dependency in imported resources. The Allied blockade and attacks on critical resources during the war had taught them how dependent they were for

critical materials such as oil. Increasing their concerns was an imbalance of trade, leaving them with a severe shortage of hard currency, and rumors that worldwide oil reserves were about to run out.[20] Germany was dependent on fuel imports for greater than 90 percent of their national requirements.[21] They had a strategic problem of the first order.

Onto the stage stepped Adolph Hitler. Obsessed with many things following the Great War, Hitler outlined his beliefs in his book *Mein Kampf*.

> The foreign policy of a People's State must first of all bear in mind the duty of securing the existence of the race which is incorporated in this State. And this must be done by establishing a healthy and natural proportion between the number and growth of the population on the one hand and the extent and resources of the territory they inhabit, on the other. That balance must be such that it accords with the vital necessities of the people.
>
> What I call a *healthy* proportion is that in which the support of a people is guaranteed by the resources of its own soil and subsoil. Any situation which falls short of this condition is none the less unhealthy even though it may endure for centuries or even a thousand years. Sooner or later, this lack of proportion must of necessity lead to the decline or even annihilation of the people concerned.[22]

One of his eight key goals for Germany was identified as economic sufficiency through a large area autarky.[23] German self-sufficiency was not the goal.

> Sensible autarky called for a fundamental turn in foreign-trade policy; in the final analysis it implied that no more should be exported than was required for the importation of indispensable raw materials and foodstuffs and of such commodities as were 'unavailable or available in insufficient measure' or could not be manufactured in Germany in sufficient quantity.[24]

Hitler essentially wanted reciprocal-bilateral economic agreements with his trade partners to establish a barter mechanism—to eliminate trade imbalances creating hard cash issues.[25] The desire was for a friendly and neutral ring of trade partners within easy reach of Germany. Being close made it possible for the Nazis to easily reach out and *negotiate* with their military should a partner decide to terminate their trade agreement before Germany was ready to do so.

The role of oil and fuel cannot be understated when talking about German and Nazi views regarding their national economy or their military plans for the future. Hitler was obsessed with oil. To Hitler, it was the vital commodity of the industrial age and for economic power.[26] The Germans had a large growing population and needed mechanical farming systems fueled by oil products to help feed them. They also knew they had a crucial need for oil products to rebuild and fuel German military forces for the upcoming struggle Hitler had planned to achieve his expansionist aims. The war of 1914 to 1918 taught him that it was imperative to have sufficient economic resources. In 1934, Hitler assigned Wilhelm Keppler, his personal economic advisor, to find replacements for imported resources. Keppler had been working closely with big business since Hitler's rise to power, creating a working group known as the Keppler Circle whose task was to develop alternative economic programs.[27] The result was the inclusion in a Secret Four Year Plan memorandum of a strategic objective to increase domestic mineral oil production to self sufficiency within 18 months and to satisfy lubricant requirements by processing coal.[28]

The Nazis never quite reached the 3.8M ton goal they set for themselves as can be seen in Table 1.[30] Contrary to the almost mythological stories of Teutonic efficiency, the Germans were not a totalitarian state in regard to everything in their economy. The business economy was capitalistic in nature, although strongly monitored, encouraged and incentivized by supportive government contracts.

> The economic system introduced step by step after 1933 may be assigned to the 'guided-market economy' or 'organized capitalism' type: the state set the economic goals, it laid down the economic priorities, it even acted on a considerable scale as the customer, i.e. generally as a directing agency, while entrepreneurs managed their business on their own responsibility in line with the state's directives. The National Socialists felt under an obligation to 'observe the intrinsic laws of all economic matters' because they feared that any violation of these might have to be paid for dearly in economic terms.[31]

By the time the war started in 1939, the incentives allowed the development of an additional 14 FT and Bergius plants, with 6 more under construction.[32] These plants provided a key edge to the German economy and to the Luftwaffe in particular.[33] About 95 percent of Germany's total aviation gasoline for the Luftwaffe was provided by the Bergius hydrogenization plants during the war. Without them the Luftwaffe could not have gotten off the ground.[34] Toward the end of the war, these plants were key in keeping Germany in the war. By 1943, synthetic fuel production had doubled from 1942 levels, producing 124K barrels a day. By early 1944 it was providing 57 percent of the total oil supply and 92 percent of aviation fuel. All told, synthetic fuels would account for half of all of Germany's oil production.[35]

Another interesting myth regards Germany's *total war* effort; namely that they sacrificed everything for the fatherland. During the war, all the Allies made this assumption because of their own conservation efforts. While some sacrifices were made by the Germans, analysis after the war revealed a very different picture.

> Germany did not fight a total war; despite all the propaganda talk, she made no serious attempt to exploit her own war potential fully, except perhaps for a brief period in August and September 1944, when it was too late to be of any consequence. Whatever ruthlessness she may have shown towards vanquished enemies, there is no evidence of ruthless sacrifices having been imposed upon her own people for the sake of victory; in terms of the thoroughness of the war effort, Germany lagged well behind not only Britain or Russia in the present war, but also behind her own showing in the First World War. Whatever else may be said about the German economy it certainly was not *totalitarian*.[36]

Some of the potential to conserve can be seen in the split between civilian and military consumption (see Table 2). The military would never have been given 100 percent, as some amount is always needed in the logistical tail supporting production and transportation, not to mention essential civilian

Years	Tons (millions)
1939	1,091.8
1940	1,430.2
1941	1,994.0
1942	2,603.2
1943	2,913.7
1944	1.673.4

Table 1. German Synthetic Oil Production 1939-1944[29]

usage. Nonetheless, there was a considerable amount available to further bolster the military war machine in its strategic and operational efforts. It can only be imagined what Germany would have done and what battles could have been changed with more fuel for its blitzkrieg style of warfare. The military constantly adjusted its pattern of behavior and consumption to match the available fuel supply situation of the moment. This meant reducing its usage of fully motorized units and heavy bomber forces, thus reducing its strategic and operational capability.[38]

Destruction of Germany's oil production capability played a crucial role in the demise of the Third Reich. Once the Allies had destroyed much of the German airpower, it turned its attention to oil production facilities, making them a priority target. Starting in April 1944, the attacks grew. On May 12, the Eighth Air Force attack with 935 planes hit the fuel plants in central and eastern Germany. The bombing results rocked the Nazi production czar Albert Speer. "The enemy has struck us at one of our weakest points. If they persist at it this time, we will soon no longer have any fuel production worth mentioning. Our one hope is that the other side has an Air Force staff as scatterbrained as ours!"[39] On June 8, 1944, attacks on the German oil industry commenced with a vengeance when General Carl A. Spaatz sent his historic cable to his Air Force commanders: "Primary strategic aim of US Strategic Air Forces is now to deny oil to enemy air forces."[40] German synthetic production dropped from its average 316K ton monthly production before the start of Allied bombing in April 1944 to 5K tons in September.[41] The loss of fuel during this time period seriously hampered everything from pilot training to the movement of Panzer divisions in the field. "[Speer's] visit to the Ruhr during early November, coming on the heels of a new wave of allied air strikes against Germany's synthetic fuel plants and its railways and canals, rocked his confidence."[42] By December, Albert Speer, the Nazi Minister of Armaments, stated that the fuel shortage had reached catastrophic proportions. The lack of fuel continued hampering the German army for the rest of the war, debilitating their ability to either attack (Battle of the Bulge) or defend (Baronov bridgehead at the Vistula).[43] After the surrender, Field Marshal Milch stated "If the synthetic oil plants had been attacked 6 months earlier Germany would have been defeated 6 months earlier."[44]

The Allies saw synthetic fuel as so vital to Germany's ability to wage war that German synthetic fuel production was prohibited by the Potsdam Conference on 16 July 1945.[45] Fuel processing facilities were a critical vulnerability for Germany's support of its center of gravity—the Wehrmacht.[46] The investment in synthetic fuels undertaken by Germany allowed it to continue fighting years longer than reasonably expected for such an isolated and resource *poor* nation.

Years	Gross-Deutsch-land and Occupied Countries* Production (000 tons)	Total German Consump-tion (000 tons)	Portion Used by Armed Forces (000 tons)
1049	3,963	5,856	3,005
1941	4,839	7,305	4,567
1942	5,520	6,483	4,410
1943	6,563	6,971	4,762
1944	4,684	-	-
* does not include the Axis *satellites, such as Romania*			

Table 2. German Petroleum Production and Use 1940-1944[37]

Strategic Lessons

There are five key lessons that can be learned from the German experience. They should be recognized as paramount to developing an alternate energy strategy.

1. Recognize and admit you have a problem. The earlier the better, especially if technology is involved. It takes time for a new technology to mature to the point where it is both dependable and economically viable.

It became apparent to Frederich Bergius and others at the start of World War I that oil and oil products were becoming a necessity for the machines of modern warfare. Bergius came to the conclusion that his coal hydrogenization process would address this critical requirement. As a result, he organized a group of investors to start commercial development. As noted earlier, technical difficulties, gaining access to the Romanian oil fields, and the end of the war prevented this enterprise from succeeding during the war.[47]

As Hitler came to power in 1932, a discussion with I. G. Farben (who controlled Bergius' hydrogenization process) brought the availability of a German domestic oil alternative to his attention. He immediately grasped the impact to his center of gravity—the Wehrmacht. Synthetic fuel production became one of the keystones of German economic plans between 1936 and 1945.[48]

Hydrogenization and the FT process both had sufficient time to develop and mature into viable commercial processes, capable of having a national strategic impact. Early problem recognition allowed this to occur.

2. Commit to a course of action. General George Patton's famous quote "A good plan violently executed now is better than a perfect plan executed next week"[49] could not be more true. Waiting until you are having a perfect plan to deal with an emergency before you take action will obviously put you behind the power curve. When a process must be done on a large commercial scale, it requires considerable capital investment and may take several years to build. Spending time arguing over the benefits of any particular technology is time wasted.

Hitler's 1932 commitment to commercial synthetic oil development was critical in the construction of 14 plants by September 1939 (6 more under construction). Were the processes involved perfect? Far from it! They were very inefficient using about 5 tons of hard coal or 10 tons of lignite to produce 1 ton of synthetic fuel.[50] More importantly, the processes worked on a commercial scale (Germany had plenty of coal). The synthetic fuel plants were vital to the German war economy supporting the Wehrmacht and Blitzkrieg. Blitzkrieg was a new warfare concept built on mechanical speed to outmaneuver its often numerically superior opponents, striking a knockout blow before their enemy was prepared.[51]

Before invading Russia in 1941, sufficient fuel reserves were available to allow the German military significant freedom of action and maneuver. As the war progressed, Allied attention began to focus more and more on the oil resource areas. When

Germany started losing the ability to maneuver freely due to lack of fuel, they lost their ability to take tactical advantage of a given set of circumstances. Oil became a critical limiting factor. Without the additional operational capability that 11,706.3M tons[52] of synthetic fuel brought to the German war machine from 1939 to 1944, the war could arguably have been over much sooner.

3. Support existing developmental and technology efforts. Everybody looks for the *silver bullet* to solve their problem—that one thing that makes the problem disappear. Mankind has been lucky with two energy sources—coal and oil. Both have worked in a fairly universal manner to meet mankind's energy needs in many ways. Future developments may not be so universal, but that is not necessarily bad. It just requires adaptation to what works for a particular set of circumstances.

Just as the Germans supported both the FT and hydrogenization in their quest to replace oil, the US should support multiple solution alternatives. Encouraging multiple techniques simplifies goal achievement by allowing a simpler technique to satisfy a simpler requirement. It diversifies the risk by isolating the possibility of failure to individual processes. Finally, diversification allows for increased opportunities to identify and implement tailored process efficiencies for a particular energy product.

The Germans did not launch a program to find a single replacement for oil. They moved forward from where they found themselves, taking advantage of both FT and hydrogenization processes to meet their strategic needs. Sounding similar in capability, the processes were actually complementary in that hydrogenization was better suited to the manufacture of high octane aviation fuel and FT for diesel and heavier petroleum products.[53] Each supported a highly important niche for the German Wehrmacht—aviation fuel for the Luftwaffe and diesel for the Panzer divisions and general transportation.

4. Conservation can make a difference. Conservation is recognized by most experts as the first course of action to increase availability of any scarce resource. It is usually the only alternative that can have nearly immediate results. In the short-term, rationing is typically the instrument used—ration books, limiting use to key people and industries, or some type of luxury tax. Long-term solutions to stretch existing supply levels or reduce overall consumption levels are usually associated with finding more efficient ways to utilize the resource or limit (or eliminate) the need for the resource.

Germany did not seriously begin considering conservation until 1942.[54] Considerably more fuel could have been made available to the German military (see Table 2). Some was certainly needed for military support infrastructure, but more could have been made available for direct military operations.

Studying the German fuel picture during World War II is fascinating. At most points in time, they never had more than a few months strategic reserve. Captured fuel from countries such as France (785K tons) and purchased fuel from their allies such as Russia (900K tons with the 1939 pact) allowed them to take the next operational or tactical step.[55] The Germans lived just ahead of their oil demand curve all through the war. Hitler did not believe in the necessity of stockpiling and "emphatically demanded that full economic mobilization should neglect long-term stockpiling and confine itself to sufficient armaments, equipment, and food supplies."[56] Hitler did not expect to fight a protracted war, but a series of small ones—if he could not intimidate his opponents by military threats alone.[57] The Wehrmacht also learned to live with this shortage, taking it into account in their tactical and strategic battle planning as any army would do. Although subject to much speculation, the lack of readily available fuel has to be assumed to have resulted in missed opportunities for battlefield success.

> The situation changed in 1941 with the German attack on Russia, an attack launched with the objective of obtaining the Russian oil resources for Germany. This attack failed mainly because of the slender nature of the German liquid combustible resources which only allowed for the concentration of three and a half million Germans for the initial attack. Had the Germans had the means in 1941 to throw against the Soviet Union at least 5 million men with their equipment, the German campaign in Russia in 1941, given the almost total Russian unpreparedness for the attack, would have achieved its purpose (another short war).[58]

The US is a major oil consumer with very (energy) inefficient cars and houses. American oil consumption history shows the effect of conservation after the start of corporate average fuel economy (CAFE) vehicle mileage standards in 1975. By about 1983 (see Figure 1), just a few years after the start of CAFE requirements, a 20 to 25 percent reduction in consumption was achieved. Unfortunately, this success was not followed by additional conservation accomplishments because of a lack of political support for continued CAFE mileage reductions.[59]

5. Establish a strategic framework focused on successful results. It is easy to get lost in the details, such as discussing how a technology works, arguing pros and cons, arguing the benefits or lack thereof for a particular constituency, location, or industry. It is just as easy when the next new technology or process comes along to repeat the same discussions all over again—hopefully reaching new decisions that do not contradict earlier efforts. What is more difficult, yet more beneficial, is developing and implementing a strategic framework focused on the desired results, not a desired technology. As an example, this framework must contain the following:
   - Identify the desired outcomes: internally sourced, renewable fuels
   - Establish desired control limits or mechanisms: minimized CO_2 emissions
   - Cultivate emerging technologies, encouraging source and process diversity: invest in research and development—multiple specialized processes for multiple materials
   - Nurture initial life cycle start-up success with economic support: research and development grants, tax incentives, purchase guarantees

Because of the economic and wartime nature of their oil requirement, Nazi Germany did not recognize the need for several of the elements of this framework. They were not concerned about the environment and, although cost was an issue, they recognized that Germany needed an internal source of oil. Further, higher than competitive costs within Germany helped with their balance of trade (hard currency) issues and assured a fuel supply in time of war or conflict.

Current US Energy Efforts

What has the US done to reduce its strategic dependency on foreign oil? The first significant national activity occurred after the 1973 Arab oil embargo. A public car mileage framework was established under CAFE standards in 1975. This did achieve improvements in overall consumption as was noted earlier, but continuing progress was not achieved after 1984. Congress did not require additional increases in vehicle mileage until 2008.[60] Overall consumption has continued to rise.

President Bush's administration has been formulating energy policy and supporting legislation since early in his first term. The President released his energy policy in 2001 and it included three principles:

- The policy is a long-term, comprehensive strategy. Our energy crisis has been years in the making, and will take years to put fully behind us.
- The policy will advance new, environmentally friendly technologies to increase energy supplies and encourage cleaner, more efficient energy use.
- The policy seeks to raise the living standards of the American people, recognizing that to do so our country must fully integrate its energy, environmental, and economic policies.[61]

The energy effort slowed down after 11 September 2001 as the United States found itself embroiled in the Global War on Terror (GWOT). Although Congress did try to develop energy bills in 2002 and 2003, the nation's focus was on the GWOT and the US-led invasion of Iraq. The bills died in conference before being offered to Congress for their consideration and the effort had to start over.

In 2005, Congress did pass a fairly comprehensive energy bill which was signed into law by President Bush on August 8th. The bill which provides for $88.9B over 10 years[62] was primarily focused on continued use of fossil fuels, but it did include several provisions totaling nearly $13.8B regarding the area of renewable fuels, including about $5.3B for hydrogen-related production research. Although some provision was made for fuel efficiency tax credits, the bill failed to strengthen fuel economy standards (CAFE). It has been noted by the Union of Concerned Scientists that this decision will increase US gas consumption by 10 billion gallons through 2015 and will ironically wipe out the gains to be realized by the President's proposed changes to the fuel economy regulation.[63]

The President continued to push energy in his 2006 State of the Union address with the Advanced Energy Initiative proposal. This initiative called for reduced dependence on foreign energy, improvement in energy efficiency, and enhanced energy security by changing the way America fuels its vehicles.[64] The Initiative's goals covered vehicles and homes-business energy usage.

Fueling Our Vehicles

- Develop advanced battery technologies that will allow a plug-in hybrid-electric vehicle to have a 40-mile range operating solely on battery charge
- Foster the breakthrough technologies needed to make cellulosic ethanol cost-competitive with corn-based ethanol by 2012
- Accelerate progress towards the President's goal of enabling large numbers of Americans to choose hydrogen fuel cell vehicles by 2020

Powering Our Homes and Businesses

- Complete the President's commitment to $2B in clean coal technology research funding, and move the resulting innovations into the marketplace
- Develop a new Global Nuclear Energy Partnership to address spent nuclear fuel, eliminate proliferation risks, and expand the promise of clean, reliable, and affordable nuclear energy
- Reduce the cost of solar photovoltaic technologies so that they become cost-competitive by 2015, and expand access to wind energy through technology[65]

This initiative was followed in early 2007 with Executive Order 13423, mandating US agencies to decrease petroleum consumption 2 percent each year through 2015 and increase alternative fuel use by 10 percent each year. At the 2007 State of the Union speech, the President announced his *20 in 10* goal. Recognizing America's addiction to oil, he asked that the US reduce its gasoline use by 20 percent over the next 10 years.[66] A major part of the program is to increase the supply of renewable and alternative fuels by 35 billion gallons per year by 2017. The effort includes additional requests for research and development funding to evaluate the Biomass Program and intermediate ethanol-gasoline blends such as E15 (15 percent ethanol) and E20 (20 percent ethanol) to accelerate gasoline displacement.[67]

The President continued pushing the Energy Security Program with his 2008 budget submission. His request to Congress included provisions for alternative fuels for cars and trucks, improving and reforming CAFE standards, accelerating the Advanced Energy Initiative, expanding the Strategic Petroleum Reserve, accelerating the American Competitiveness Initiative (supports basic research to enable future technology breakthroughs), and strengthening American nuclear weapons storage and nonproliferation capabilities.[68]

In November 2007, The US Department of Energy's Energy Efficiency and Renewable Energy Division, Office of the Biomass Program, released a comprehensive plan regarding the development of a renewable energy source, the "*Biomass Multi-Year Program Plan.*" The comprehensive nature of the plan should not be understated. It covers all aspects from production of feedstocks (raw material inputs), feedstock logistics, biofuel production, distribution, and biofuels end use technologies.

The approach pictured in Figure 3 allows for a lot of flexibility and diversity of use, yet each supply chain element must be addressed to meet the target outcomes. Each element is summarized as follows:

- Feedstock Production. Produce large, sustainable supplies of regionally available biomass
- Feedstock Logistics. Implement cost-effective biomass feedstock infrastructure, equipment, and systems (biomass harvesting, collection, storage, preprocessing and transportation)
- Biofuels Production. Deploy cost-effective, integrated, biomass-to-biofuels conversion facilities
- Biofuels Distribution. Implement biofuels distribution infrastructure (storage, blending, transportation, and dispensing)
- Biofuels End Use. Expand public availability of biofuels-compatible vehicles offering the same performance as vehicles using traditional fuels[70]

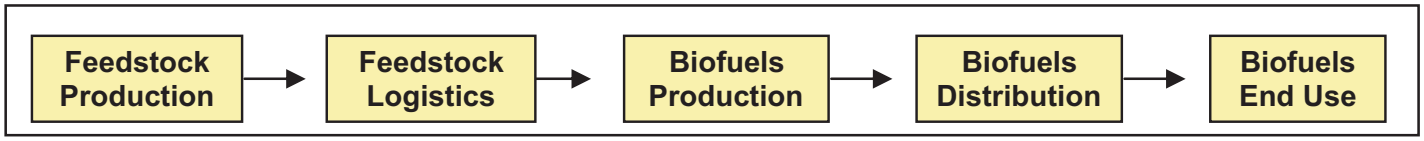

Figure 3. Biomass to Biofuels Supply Chain[69]

What might seem to be *government overkill* in such a comprehensive plan is, in this writer's opinion, a well thought out approach to covering all the critical aspects of standing up a new, emerging fuel source to start replacing a highly entrenched supply and utilization chain for imported oil related products. As noted in the Multi-Year Program Plan's (MYPP) executive summary:

> This approach ensures development of required technological foundation, leaves room for pursuing solutions to technical barriers as they emerge, enables demonstration activities that are critical to proof of performance, and lays the groundwork for future commercialization without competing with or duplicating work in the private sector. The plan addresses important technological advances to produce biofuels, as well as the underlying infrastructure needed to ensure that feedstocks are available and the products can be distributed safely with the quality and performance demanded by end consumers.
>
> The Biomass Program's MYPP is designed to allow the program to progressively enable increasing amounts of biofuels, bioproducts, and biopower to be deployed across the nation from a widening array of feedstocks. This approach will not only have a significant impact on oil displacement at the earliest opportunity, but will also facilitate the paradigm shift to renewable, sustainable energy in the long-term.[71]

December 2007 saw considerable energy related activity in the US capital. The House of Representatives initiated House Resolution (H.R. 6), a bill that would have considerable impact on the US energy source structure and which supported many of the President's biofuel efforts. But, proposed financing for the effort would come from seriously restructuring current tax law to tax American oil companies at a higher rate, due to the very high profit level they have been experiencing in recent years. It also proposed a Renewable Energy Portfolio Standard (RPS) that required electric utilities to provide a minimum amount of electricity from renewable energy resources—15 percent by 2020. While the President mostly welcomed the proposed bill, he would not support such changes. The Senate, through Senate Amendment 3850, designed a compromise essentially eliminating both oil company taxation and the RPS to ensure the bill was not vetoed by the President. The House approved the Senate bill on 18 December 2007 and the President signed the bill into law (Public Law 110-140) on 19 December 2007.

The highlights of key provisions enacted into law are as follows:

- Corporate Average Fuel Economy (CAFE). The law sets a target of 35 miles per gallon for the combined fleet of cars and light trucks by model year 2020.
- Renewable Fuels Standard. The law sets a modified standard that starts at 9 billion gallons in 2008 and rises to 36 billion gallons by 2022.
- Energy Efficiency Equipment Standards. The adopted bill includes a variety of new standards for lighting and for residential and commercial appliance equipment. The equipment includes residential refrigerators, freezers, refrigerator-freezers, metal halide lamps, and commercial walk-in coolers and freezers.
- Repeal of Oil and Gas Tax Incentives. The enacted law includes repeal of two tax subsidies in order to offset the estimated cost to implement the CAFE provision.[72]

While the signed bill left much of what the democratic House of Representatives and environmental advocates wanted on the table, it was a big step in the right direction for the United States and was landmark legislation. The bill's impact regarding fuel economy and biofuel are designed to weaken the country's exposure to volatile oil prices.[73]

Comparisons and Observations

Are the actions being taken by the United States in its pursuit of synthetic fuel to replace oil appropriate? Looking at the activities to date with regard to the five strategic lessons identified earlier, the following observations can be made.

- **Recognize and admit you have a problem.** The United States recognized the imported oil problem in 1975, but failed to continue CAFE-like efforts that would have provided some relief. Between the early 1980s and 2001, little significant activity affecting change on a national level can be noted. President Bush's administration recognized in 2001 through the National Energy Policy that the US had energy issues that needed to be addressed as a strategic imperative.[74]

  Problem recognition has *intensified* as oil prices have increased since 2001. Foreign energy dependency has become an ongoing topic of discussion within the current government and among the 2008 presidential candidates. The need to reduce or eliminate American dependency on foreign oil by finding domestic alternatives—preferably renewable and environmentally friendly has been publicly admitted.
- **Commit to a course of action.** Although the President's energy policy covers all aspects of America's energy usage profile, considerable progress has been made with regard to the potential reduction of oil imports and the strategic impact it has on the US. The President set a strategic goal for the United States in his 2007 State of the Union Address to reduce gasoline consumption by 20 percent in 10 years (20 in 10). Supporting this strategic goal, he has also set other objectives that must be achieved in order to be successful.

> To reach this goal, we must increase the supply of alternative fuels by setting a mandatory fuels standard to require 35 billion gallons of renewable and alternative fuels in 2017—nearly five times the current target. At the same time, we need to reform and modernize fuel economy standards for cars the way we did for light trucks—and conserve up to 8.5 billion more gallons of gasoline by 2017.[75]

The renewable fuels goal of the President's program appears to be most challenging as it is an emerging technology. To that end, the Department of Energy released the *Biomass*

Multi-Year Program Plan in November 2007 to enable the deployment of biomass as a renewable energy source. A good question on renewables is "How much of current American needs can it replace?" The Department of Energy and Department of Agriculture in their *Biomass as Feedstock* study is looking at about 30 percent replacement and the renewable biomass raw material is potentially there; over a billion tons annually with judicious use of technology and agricultural acumen (see Figure 4).

The other synthetic fuel source, coal, is also a potential, albeit a nonrenewable alternative, but has not been included in a similarly detailed plan at this time. Funding has been provided for continued research and development into the FT hydrogenization process as it is expected to be used in both coal and renewable biomass synthetic fuel efforts.

A defined course of action, at least with regard to importing oil for gasoline, has been identified and enacted by way of H.R. 6 through the new CAFE standards and the Renewable Fuels Standard for use of increasing amounts of ethanol. A focus on the transportation sector is needed (see Figure 5) since it uses nearly 75 percent of total daily petroleum flow. In particular, the personal transportation sector which is responsible for 50 percent of the imported oil in the form of motor gasoline.

- **Support the existing developmental and technology efforts.** The Biomass Program is a collaborative effort with industry to advance both biomass feedstock and conversion technologies. It will involve public-private partnerships to demonstrate the large-scale, integrated biomass technologies involved and will accelerate market deployment infrastructures to make the products commercially available.[78] The program is intended to build on existing technologies, improving and making them economical for large scale, long-term production efforts. It will also be taking similar technologies and integrating them in a new way called a biorefinery (see Figure 6) that can convert any number of biomass feedstocks into fuels, power, and chemicals. This new concept can be compared to today's petroleum refineries which produce multiple fuels

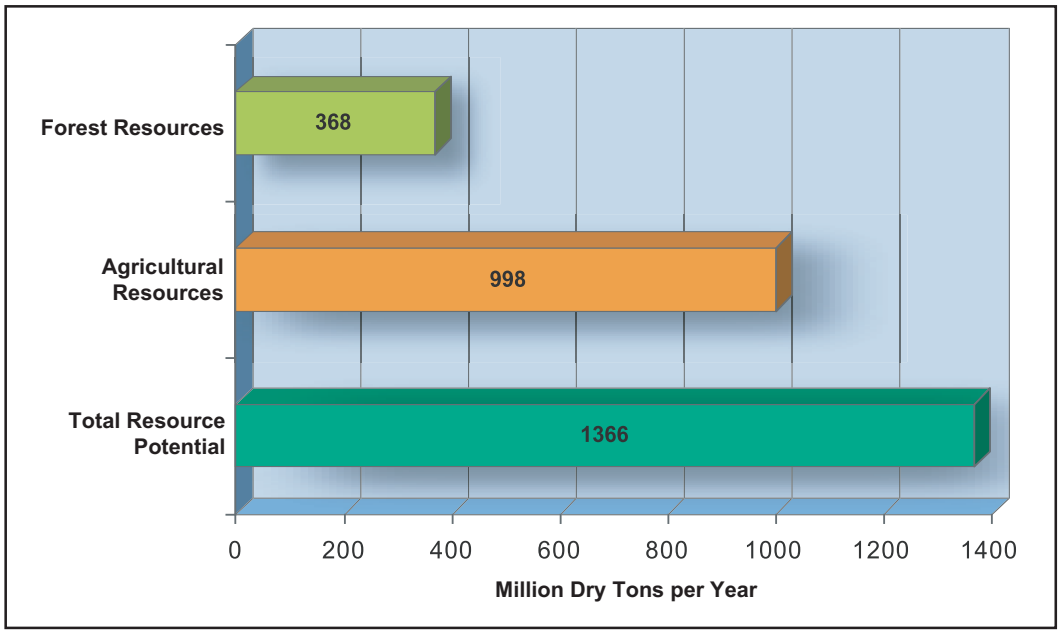

Figure 4. Annual Biomass Resource Potential[76]

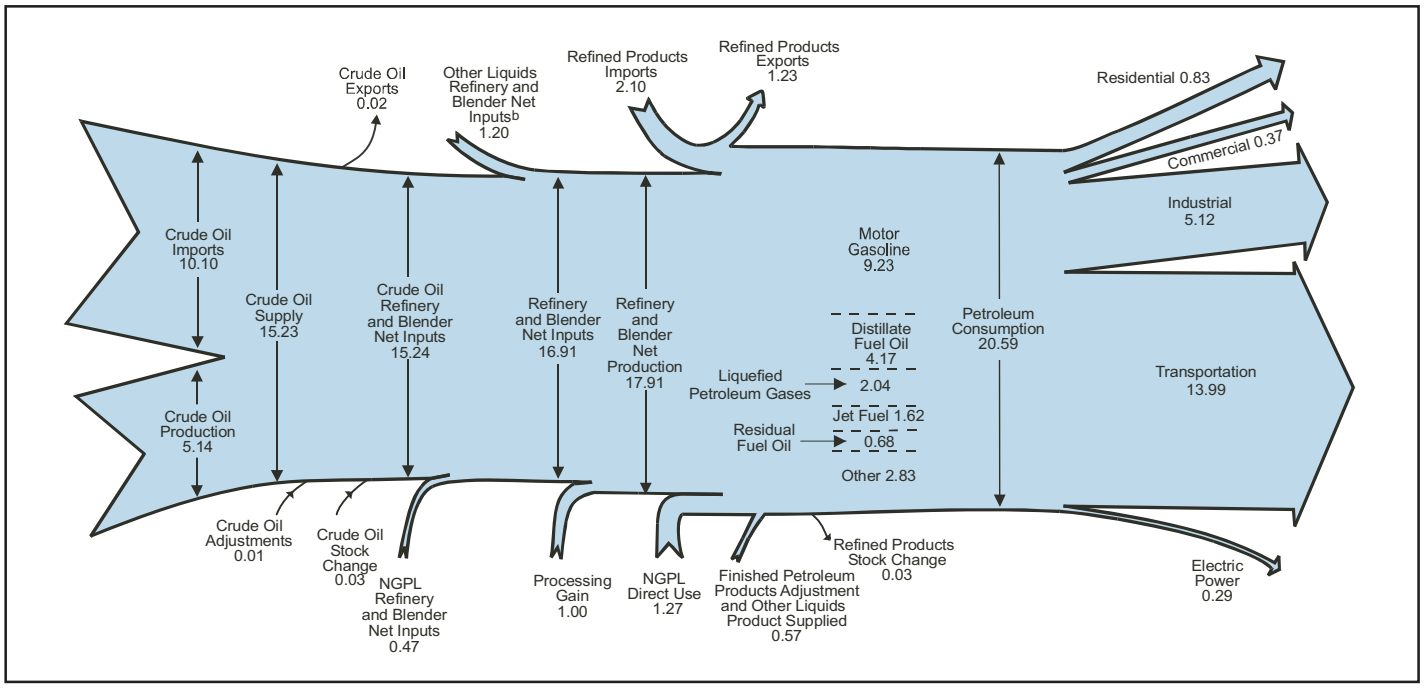

Figure 5. Petroleum Flow 2006[77]

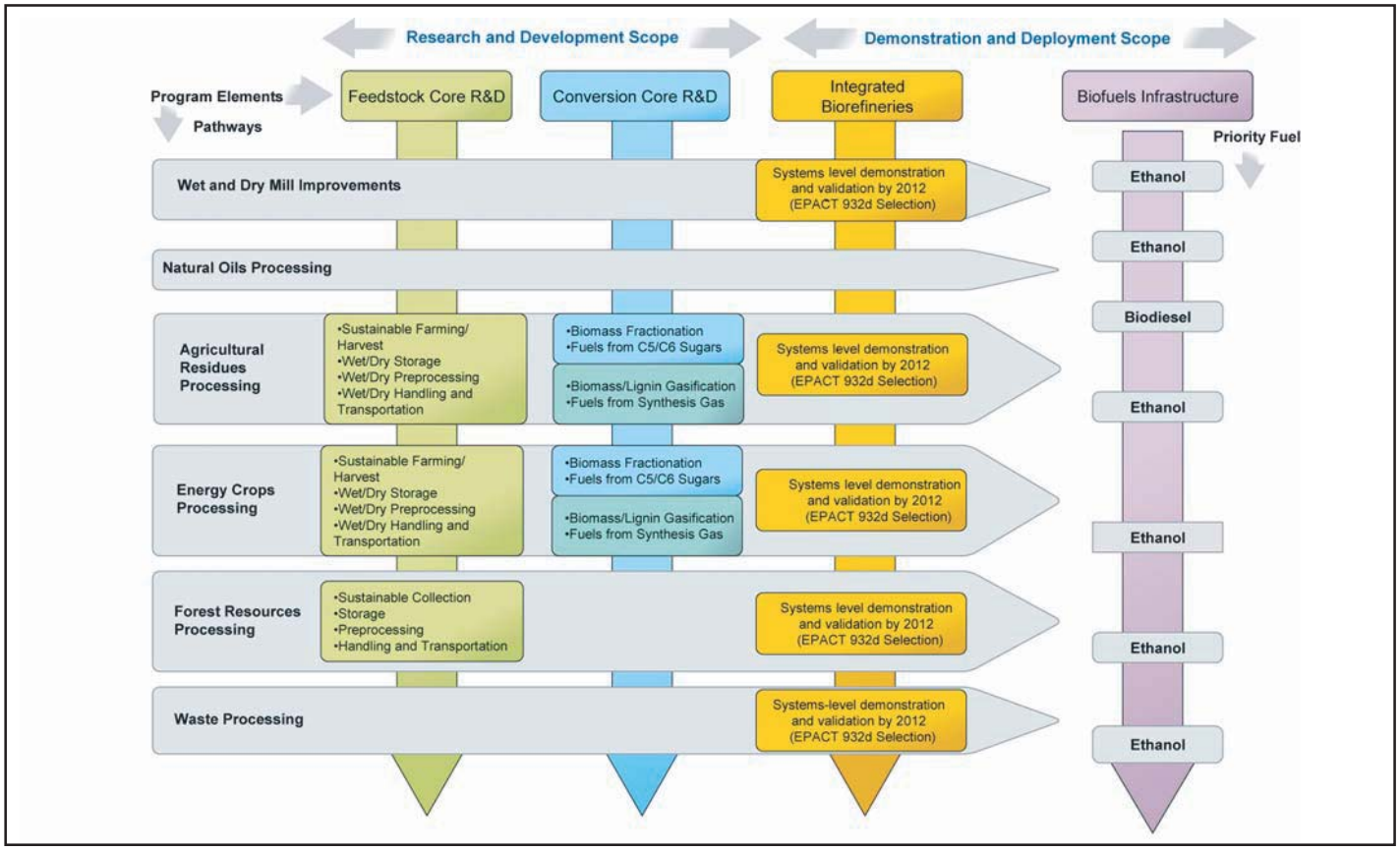

Figure 6. Technical Element Links to Biorefinery Pathway Framework[79]

and products from crude oil.[80] The difference here will be multiple input source materials rather than one, each going through their own *independent* conversion process, converging where the process and technology allow.

At the time of this writing, it is difficult to determine the true impact H.R. 6 will have on biofuels and cellulosic ethanol production in particular. The funding for research and development (R&D) in the bill is minimal ($25M for biofuel grants and $2M for renewable energy technologies), but the requirement to use 21 billion gallons of cellulosic ethanol by 2022 puts most of the R&D onus on industry.

- **Conservation can make a difference.** New CAFE standards have been legislated in H.R. 6, along with new energy efficiency standards for lighting and for residential and commercial appliance equipment. Each of these actions will reduce overall energy consumption in the long-term. As was shown earlier in this article, conservation could be making a *significant* contribution to reducing American oil imports within just a few years. With oil prices continuing to rise, conservation should be able to provide relief in the relative near-term. The potential can be seen looking at the nominal price per barrel over time and the total import cost for the United States as of 2006 (see Figures 7 and 8). Immediate gasoline conservation is called for, but no immediate action is being taken. Achieving a fleet average of 35 miles per gallon by 2020 will be a significant accomplishment but does very little to provide near-term relief to the import oil issue or help the current economic issues driven by imported oil costs.
- **Establish a strategic framework focused on successful results.** The Biomass Program has three broad areas: core research and development; industrial scale demonstration and validation; and cross-cutting market transformation activities. The program has taken the wide variety of biomass feedstocks and conversion technologies and placed them into seven plausible pathway options within the biorefinery construct. The approach taken is intended to streamline evaluation of opportunities, establish priorities for R&D, and measure commercialization progress. Although not shown as milestones in Figure 9, life cycle cost-benefit analysis and environmental impacts will also be addressed.

The most interesting thing about the MYPP may be the infrastructure transformation activities. A considerable amount of change management thought has gone into this particular area to help move toward a successful outcome. It addresses everything from the environment to the consumer to international partnerships.

With regards to renewable biofuels, a starting point, a strategic framework focused on successful results, has been defined. This is the crucial first step in American politics, defining a proposed policy. The next crucial step is funding the policy to a successful conclusion. However, that appears to be a potentially critical shortcoming of the current effort.

Conclusion

German scientists developed synthetic fuel processes before World War I and early oil shortage recognition by Bergius led to starting commercial development. Prior to World War II, Germany saw the Wehrmacht sustainment possibilities of synthetic fuel and the government incentivized a considerable number of commercial plants to provide internal sources of oil

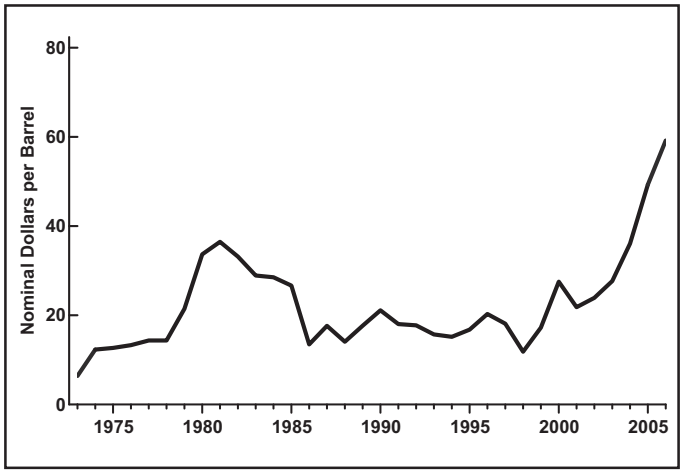

Figure 7. Nominal Crude Price 1973-2005[81]

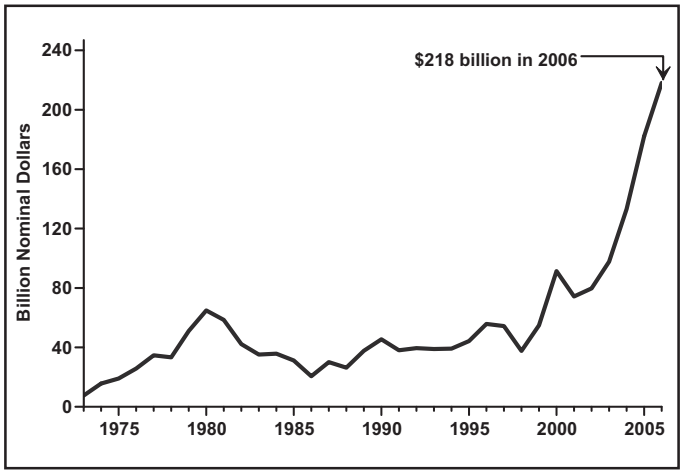

Figure 8. Nominal Crude Cost 1973-2005[82]

products. These synthetic fuel plants provided sufficient products for Germany to fight far beyond what was expected, given their lack of internal oil resources.

The United States' own shortages in domestic oil sources indicate sufficient similarity of circumstances to warrant seriously considering the lessons to be learned from the German experience over 60 years ago. They are simple, but still viable in today's world.

- Recognize and admit you have a problem
- Commit to a course of action
- Support the existing developmental and technology efforts
- Emphasize conservation
- Establish a strategic framework focused on successful results

They have great applicability to determining if the United States is moving in the right direction with regard to its energy program. When a comparison is made to the actions taken to date it indicates that America may have admitted it had a problem over 30 years ago, but has been very slow to commit to a long-term course of action to address the problem. The extensive current activity around biofuels is foundational, but the nation's resources have not been sufficiently committed. Congressional funding does not appear to be robust enough to encourage the capital investment needed to ensure long-term success. The current administration's efforts and those of Congress are a good start, but a start only. America imports nearly 66 percent of its petroleum needs every day. Biofuels will replace about 30 percent of current US petroleum consumption.[84] The remaining 36 percent will have to be addressed as well—renewable sources may be preferred, but if those renewable sources are incapable of freeing the US from its imported oil dependency, other methods are clearly available and in most cases commercially viable with today's volatile oil prices. Also remaining are residential and commercial power issues and whether this will be addressed by clean-coal technology or by nuclear power stations.

Timing is also an issue. The extended time frame being used with the current efforts, especially conservation, may only cover future growth in national energy demands. This means current plans would only preclude additional large increases in crude oil import requirements—not necessarily drive import reductions in the near-term. Building a new infrastructure for biomass based fuels may take some time, but conservation efforts in the transportation sector would be of greater immediate benefit. New CAFE standards were overdue, but are not aggressive enough to be of any near-term assistance to alleviating oil import imbalance driven inflation on America's economy or improving national security.

Finally, improving current processes, exploring other existing technologies, and developing new ones should be continued and nurtured. Biomass fuels need cheaper enzymes to help break down the cellulose for processing. Nanotechnology might be used to develop artificial enzymatic biomass factory processes to manufacture ethanol or other petroleum products. Some commercial use could be found for all the carbon dioxide to be produced by clean-coal technology—possibly in a new build material such as current concrete or wall board or bricks. Other energy renewables such as wind, tidal, and solar show potential as the technology evolves.

The bottom line is America has recognized the need and is beginning to transform its energy infrastructure. Now is the time to continue addressing the problem and finding true long-term solutions to assure national security and remove the volatility that importing vast amounts of oil has on the American economy. As Winston Churchill stated, "This is not the end. It is not even the beginning of the end. But it is, perhaps, the end of the beginning."[85]

Notes

1. James Molony Spaight, "The War of Oil," *Military Affairs,* 1949, 138.
2. George W. Bush, "2007 State of the Union Speech to the US Congress," Washington, DC, 23 January 2007.
3. US Department of State, *The National Security Strategy of the United States*, Washington, DC: White House Office of Communications, March 2006, 26-27.
4. George W. Bush, 2007.
5. Energy Information Administration, *Annual Energy Outlook 2008*, Washington, DC: US Department of Energy, December 2007, 3.
6. Fred Charles Ikle, *Every War Must End*, New York, NY: Columbia University Press, 2005, 4-5.
7. Energy Information Administration, *Annual Energy Review 2006*, Washington, DC: US Department of Energy, June 2007, 1-2.
8. John Deutch and David G. Victor, *National Security Consequences of US Oil Dependency*, Independent Task Force Report No 58, New York, NY: Council on Foreign Relations, 2006, 19.
9. Deutch and Victor, 16.
10. US Government Accountability Office, *Crude Oil - Uncertainty About Future Oil Supply Makes It Important to Develop a Strategy for*

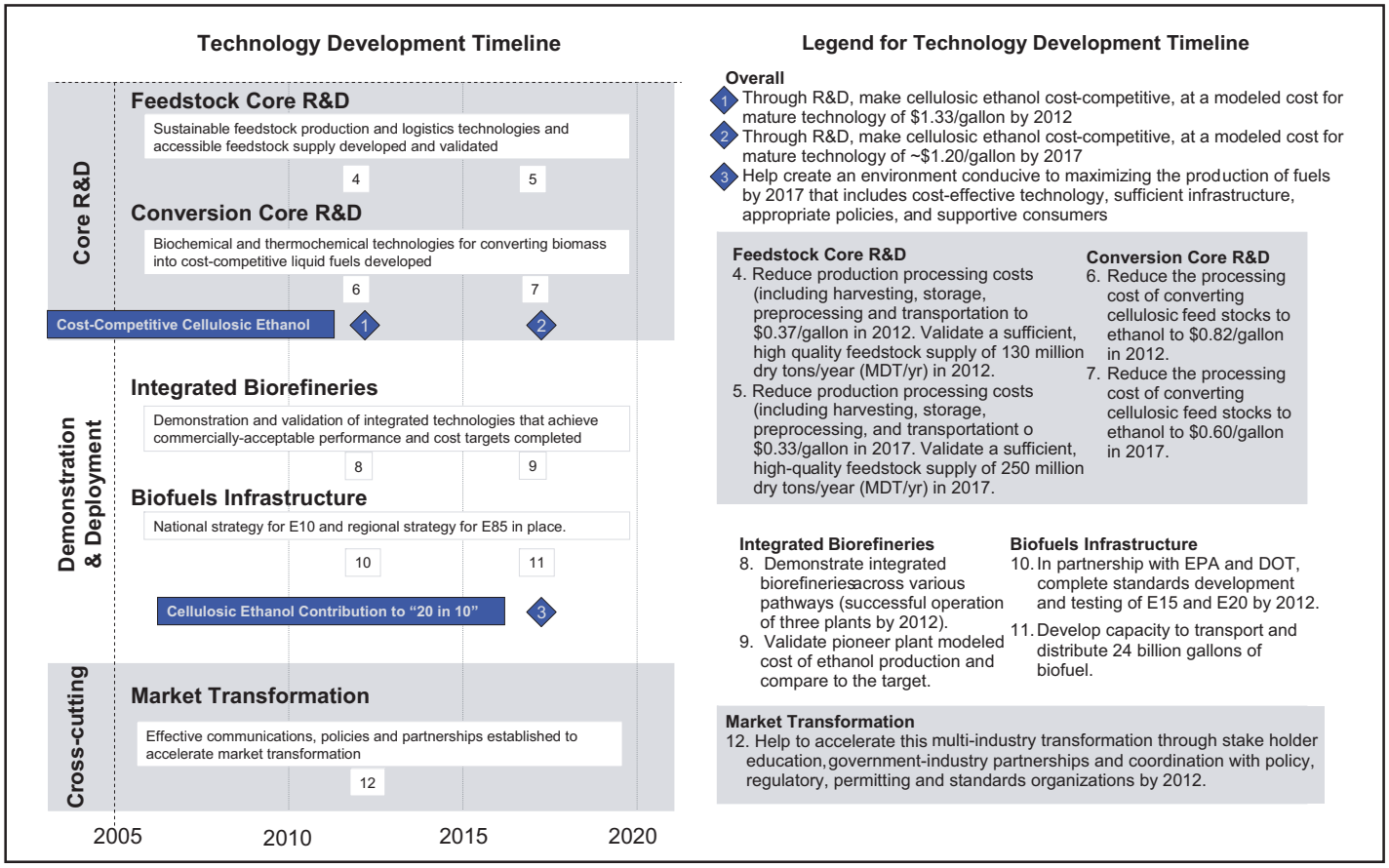

Figure 9. Biomass Program Strategy for Technology Development[83]

Addressing a Peak and Decline in Oil Production, GAO Report to Congressional Requestors, Washington, DC: Government Accountability Office, February 2007, 6.

11. Anthony N. Stranges, "Friedrich Bergius and the Rise of the German Synthetic Fuel Industry," *Isis* Vol 75, No 4, December 1984, 665.
12. Paul Roberts, *The End of Oil - on the Edge of a Perilous New World*, New York, NY: Houghton Mifflin Company, 2005, 59-64.
13. Energy Information Administration, *International Energy Outlook 2007,* Washington, DC: US Department of Energy, May 2007, 20.
14. US Department of Energy, "World Marketed Energy Fuel Use by Fuel Type 1980-2030," [Online] Available: http://www.eia.doe.gov/oiaf/ieo/excel/figure_11data.xls.
15. House Resolution (H.R.) 6,*The Energy Independence and Security Act of 2007 [Summary]*, [Online] Available: *energy.senate.gov/public/_files/RL342941.pdf* , 19 December 2007, 2.
16. John M. Broder, "Senate Approves Energy Bill without Tax Increase," [Online] Available: http://www.nytimes.com/2007/12/13/washington/13cnd-energy.html?
    a. "Separately, Congress reached a tentative agreement on a major energy package that it plans to enact outside the energy bill, according to a Senate Democratic staff member. The agreement, to be included in a broad government spending bill, would authorize the Energy Department to guarantee loans for various energy projects, making financing far easier.
    b. The agreement would guarantee loans of up to $25B for new nuclear plants and $2B for a uranium enrichment plant, something those industries had been avidly seeking. It would also provide guarantees of up to $10B for renewable energy projects, $10B for plants to turn coal into liquid vehicle fuel and $2B to turn coal into natural gas."
17. Albert Speer, *Inside the Third Reich*, trans. Richard and Clara Winston, New York, NY: The Macmillan Company, 1970, 352.
18. Anthony N. Stranges, "Germany's Synthetic Fuel Industry 1927-1945," *Energeia*, Vol 12, No 5, 2001, 1.
19. Stranges, "Friedrich Bergius and the Rise of the German Synthetic Fuel Industry," 660.
20. Stranges, "Germany's Synthetic Fuel Industry 1927-1945," 1.
21. Stranges, "Germany's Synthetic Fuel Industry 1927-1945," 1-2.
22. Dr. Peter W. Becker, "Role of Synthetic Fuel in WW2 Germany - Implications for Today," *Air University Review*, July-August 1981, 3.
23. Wilhelm Deist, *Germany and the Second World War*, trans. Dean S. McMurry & Ewald Osers P.S. Falla, Oxford, England: Clarendon Press, 1990, 196.
24. Adolph Hitler, "Mein Kampf," Project Gutenberg of Australia, [Online] Available: http://gutenberg.net.au.
25. John Robert Bengtson, *Nazi War Aims - the Plans for the Thousand Year Reich*, Rock Island, IL: Augusta College Library, 1962, 20.
26. Deist, *Germany and the Second World War*, 178.
27. Ibid., 246.
28. Daniel Yergin, *The Prize*, New York, NY: Free Press, 1991, 334.
29. Deist, *Germany and the Second World War*, 183.
30. Deist, *Germany and the Second World War,* 262-79.
31. W. G. Jensen, "The Importance of Energy in the First and Second World Wars," *The Historical Journal,* Vol 11, No 3, 1968, 552.
32. *Ibid.*
33. Deist, *Germany and the Second World War*, 198.
34. Jensen, "The Importance of Energy in the First and Second World Wars," 549.
35. Stranges, "Germany's Synthetic Fuel Industry 1927-1945," 1.
36. Yergin, *The Prize*, 333.
37. Yergin, *The Prize*, 344.
38. Nicholas Kaldor, "The German War Economy," *The Review of Economic Studies,* Vol 13, No 1, 1945-1946, 33.
39. Jensen, "The Importance of Energy in the First and Second World Wars," 551.
40. Kaldor, "The German War Economy," 43.
41. Speer, *Inside the Third Reich*, 346-47.
42. Hanson Baldwin, "Oil Strategy in World War 2," American Petroleum Institute, [Online] Available: www.oil150.com/essays/2007/08/oil-strategy-in-world-war-ii.
43. United States Secretary of War, "United States Strategic Bombing Survey – Summary Report," 1945, 9, [Online] Available: http://www.anesi.com/ussbs02.htm#tgwe.

44. Alfred C. Mierzejewski, "When Did Albert Speer Give Up?," *The Historical Journal* Vol 31, No 2, June 1988, 394.
45. United States Secretary of War, "United States Strategic Bombing Survey – Summary Report," 8-9.
46. Spaight, "The War of Oil," 141.
47. Stranges, "Germany's Synthetic Fuel Industry 1927-1945," 2.
48. Dr Joe Strange and Colonel Richard Iron, "Understanding Centers of Gravity and Critical Vulnerabilities, Parts 1 and 2," Unpublished Paper, Air War College, Maxwell AFB, Alabama, No Date.
49. Baldwin, "Oil Strategy in World War 2."
50. Stranges, "Friedrich Bergius and the Rise of the German Synthetic Fuel Industry," 660.
51. Deist, *Germany and the Second World War*, various pages.
52. Brainy Quote, "George S. Patton Quotes," [Online] Available: http://www.brainyquote.com/quotes/authors/g/george_s_patton.html.
53. Jensen, "The Importance of Energy in the First and Second World Wars," 549.
54. Kaldor, "The German War Economy," 47.
55. Jensen, (Total amount indicated on Figure 2)
56. Stranges, "Germany's Synthetic Fuel Industry 1927-1945," 2.
57. Kaldor, "The German War Economy," 44.
58. Jensen, "The Importance of Energy in the First and Second World Wars," 548.
59. Deist, *Germany and the Second World War*, 278.
60. Burton Klein, "Germany's Preparation for War: A Re-Examination," *The American Economic Review* Vol 38, No 1, March 1948, 76.
61. Jensen, "The Importance of Energy in the First and Second World Wars," 547.
62. National Highway Traffic Safety Administration, "CAFE Overview - Frequently Asked Questions," [Online] Available: http://www.nhtsa.dot.gov/cars/rules/cafe/overview.htm.
63. Roberts, *The End of Oil - on the Edge of a Perilous New World*, 331.
64. Administration, "Cafe Overview - Frequently Asked Questions."
65. Richard Cheney, *National Energy Policy*, ed. National Energy Policy Development Group, Washington, DC: US Government Printing Office, 2001, xi.
66. Taxpayers for Common Sense, "Cost Analysis of the Energy Policy Act of 2005, by Title," [Online] Available: http://www.taxpayer.net/energy/2005EnergyBillCostAnalysis.htm.
67. Union of Concerned Scientists, "The 2005 Energy Bill,"[Online] Available: http://www.ucsusa.org/clean_energy/clean_energy_policies/energy-bill-2005.html.
68. George W. Bush, "2006 State of the Union Speech to the US Congress," Washington, DC, 31 January 2006).
69. National Economic Council (ed.), *Advanced Energy Initiative,* Washington, DC: White House, 20 February 2006, 2.
70. Bush, *2007 State of the Union Speech to the US Congress*.
71. US Department of Energy, *Biomass Multi-Year Program Plan*, Office of the Biomass Program (ed), Washington, DC: US Government Printing Office, 2007, 1-15 to 1-16.
72. George W. Bush, "2008 Budget Fact Sheets," [Online] Available: http://search.archives.gov/query-bush.html?qt=2008+budget+&charset=iso-8859-1&qc=bush2&col=bush2, 22, 23.
73. Energy, *Biomass Multi-Year Program Plan*, i.
74. Energy, *Biomass Multi-Year Program Plan*, 1-2.
75. Energy, *Biomass Multi-Year Program Plan*, iv.
76. Congressional Research Service, *Energy Independence and Security Act of 2007: A Summary of Major Provisions*, Fred Sissine (ed), Washington, DC: Congressional Research Service, 21 December 2007, i.
77. Brian Wingfield, "Senate Passes Watered-Down Energy Bill," *Forbes* [Online] Available: http://www.forbes.com/2007/12/13/energy-senate-bill-biz-wash-cx_bw_1213bizenergy.html, 13 December 2007.
78. E. Kyle Datta, Amory B. Lovins, Odd-Even Bustnes, Jonathan G. Koomey, and Nathan J. Glasgow, *Winning the Oil Endgame: Innovation for Profits, Jobs, and Security*, Snowmass, CO: Rocky Mountain Institute, 2004), xii.
79. Cheney, *National Energy Policy*, Appendix 1.
80. Bush, *2007 State of the Union Speech to the US Congress*.
81. US Department of Energy and US Dept of Agriculture, *Biomass as Feedstock for a Bioenergy and Bioproducts Industry: The Technical Feasibility of a Billion-Ton Annual Supply*, Washington, DC: US Government Printing Office, April 2005, ii.
82. Administration, *Annual Energy Review 2006*, 123.
83. Energy, *Biomass Multi-Year Program Plan*, 1-1.
84. Energy, *Biomass Multi-Year Program Plan*, 3-3.
85. Energy, *Biomass Multi-Year Program Plan*, 1-3.
86. Administration, *Annual Energy Review 2006*, 166.
87. Administration, *Annual Energy Review 2006*, 168.
88. Energy, *Biomass Multi-Year Program Plan*, iii.
89. Think Exist Web site, "Quotes of Albert Einstein," [Online] Available: http://thinkexist.com/quotation/in_the_middle_of_difficulty_lies_opportunity/10122.html
90. Agriculture, *Biomass as Feedstock for a Bioenergy and Bioproducts Industry: The Technical Feasibility of a Billion-Ton Annual Supply*, i.
91. Winston Churchill, "Speech at Mansion House - Referring to the Battle of Egypt, November 10, 1942," quoted in Eigen's *Political & Historical Quotations*, [Online] Available: http://www.politicalquotes.org/Quotedisplay.aspx?DocID=59468.

Michael E. Puckett *is a career maintenance civilian with over 27 years in depot maintenance logistics within Air Force Materiel Command. He was previously assigned to Headquarters Air Force, coordinating transformation issues for the A4/7 as part of Air Force Smart Operations for the 21st Century. At the time of the writing of this article, he was a student at the Air War College, Air University, Maxwell Air Force Base, Alabama.*

He who will not apply new remedies must expect new evils; for time is the greatest innovator.

—Viscount Francis Bacon

The final dictum of history must be that whatever excellence Lee possessed as a strategist or as a tactician, he was the worst Quartermaster General in history, and that, consequently, his strategy had no foundations, with the result that his tactics never once resulted in an overwhelming and decisive victory.

—Major General J. C. Fuller, USA

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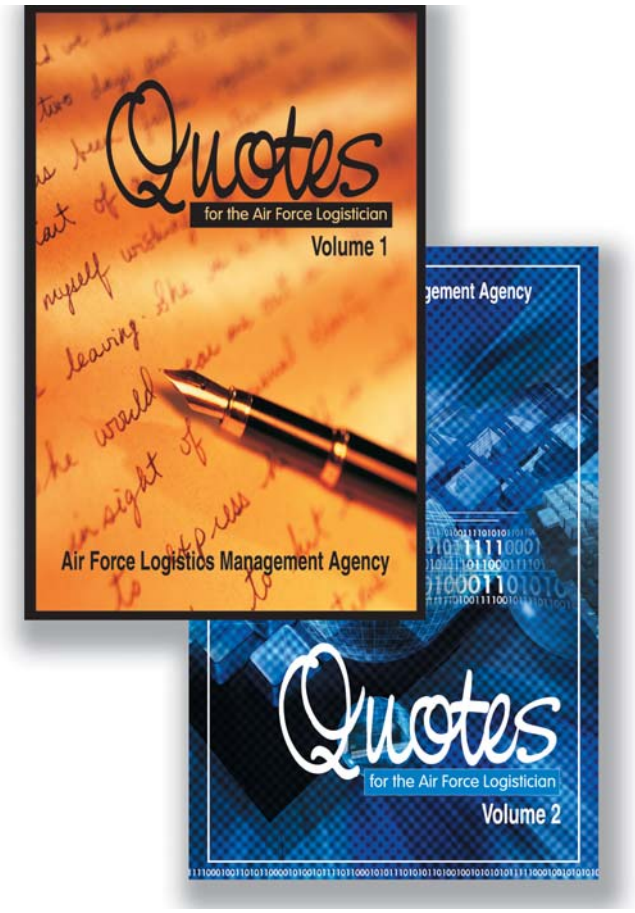

Why a set of quotations for Air Force Logisticians? An obvious answer is there isn't one. But that's not the only reason, and it's certainly not the most important reason. The primary reason for producing this set was to provide a teaching resource that can be used in classrooms, education, training, and mentoring programs for Air Force logisticians. It is a tool that can be used by instructors, teachers, managers, leaders, and students. It is also a tool that can be used in research settings and a resource that should stimulate comment and criticism within educational and mentoring settings. Copies of the set are provided free of charge to any Air Force logistician, educational institution, teacher, instructor, commander, or manager.

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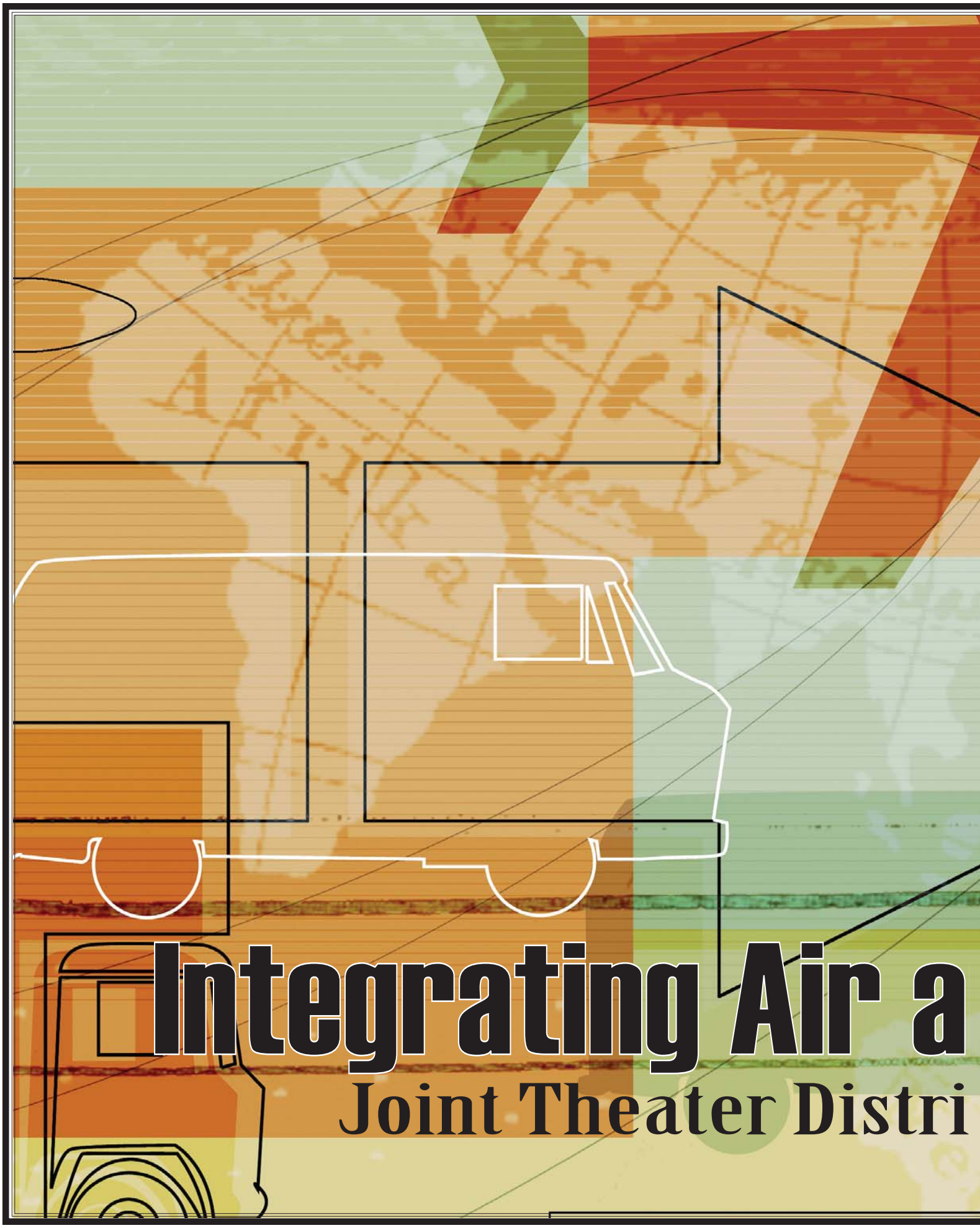

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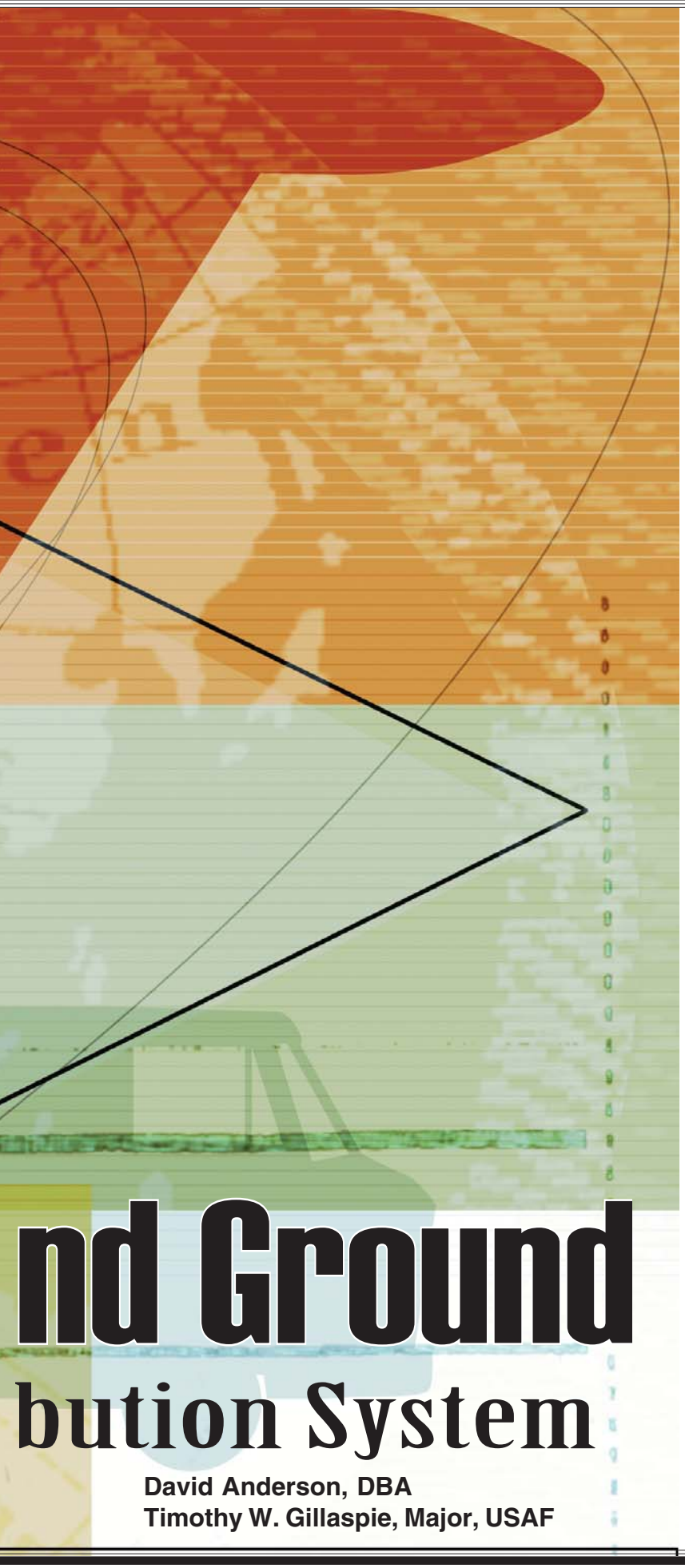

nd Ground
bution System

David Anderson, DBA
Timothy W. Gillaspie, Major, USAF

Introduction

Logistics is the lifeblood of all combat operations.

Lt Gen Henaidy, Royal Saudi Air Force

Special Feature

During the early phases of Operation Iraqi Freedom and Operation Enduring Freedom, the establishment of a multimodal distribution network was fraught with problems. The organizations required to establish the Joint theater distribution network did not exist or function as required in the case of the Joint Movement Center. Each Service established a portion of the network, but by itself did not establish the entire network. This division of labor caused seams in the Joint theater distribution network. These seams caused dramatic delays and variability in cargo and personnel delivery. V Corps had so many problems with transportation assets that the deputy commander personally approved the allocation of trucks daily. The origin of the delays was doctrine and organization centric: "Current logistics doctrine and systems do not support offensive operations across the distributed battle space."[1] Some doctrinal changes occurred in the following years, such as the creation of the Joint deployment distribution operations center (JDDOC); however, current theater organizations, information systems, and doctrine do not meet the requirements for a seamless Joint theater distribution system.

Our exhaustive research, which included a thorough review of existing distribution literature, multiple interviews, and analysis of air and ground movement data, highlight the magnitude of the problem. The reviewed literature identified a multitude of gaps in doctrine, organizations, and command and control between the Joint community and Services concerning management and execution of the distribution system, to include responsible parties and tasks. Interviews with individuals of varying ranks (captain through major general) who are engaged with theater distribution systems in multiple theaters also identified the seams created by organizations and doctrine. Their experience, coupled with analysis of movement data between locations with aerial ports in the Iraq theater of operations, further support the concept of a single command and control structure for the management of the distribution system.

Furthermore, the JDDOC, supported by Joint movement control battalions (MCB), should become the centerpiece for the management of the distribution system. The Services should retain execution responsibilities for their areas of expertise, but should make every effort to remove the need for ad hoc organizations. The ad hoc organizations typically have inadequate staffing as well as inadequate planning and assessment processes.[2]

The creation of a JDDOC for every combatant commander addresses the issue of coordinating

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Strategic airlift, now and for the foreseeable future, provides critical capabilities vital to our national interests. It is, therefore, incumbent upon the Air Force, and specifically Air Mobility Command, to work toward minimizing the amount of time our C-5s and C-17s remain broken within the airlift system.

A single command structure responsible for the movement control of the theater could better utilize available assets to meet mission requirements by selecting the mode that would be most effective for the mission. The data analysis indicated that a single Joint theater distribution, operating with true unity of effort in the management of the system, could meet the objectives of the Joint force commander—in this case, the reduction of the number of convoys conducted. For example, minimum requirements for the use of a C-130 prevent organizations from submitting cargo for air transportation, but a single organization responsible for mode selection could make decisions based on availability of all assets above echelon to use a C-130 for the movement of less than the normal requirement for use of a C-130. The single organization could also reroute cargo to an Army sherpa designated for above echelon support to meet the requirement. These decisions made by a single organization would require changes to the processes for management of the system.

Changes to the processes currently used for the management of the Joint theater distribution system need to occur. Analysis of the interviews concluded that a single or integrated information intertheater and intratheater movement; however, this organization does not address all of the issues associated with the distribution delays identified in after action reports and RAND research.[3] Current research has shown that gaps still exist between air and land components of the Joint theater distribution system. These gaps are not only organizational, but also technological. The information systems that exist today do not meet the needs of the Joint theater distribution system. We propose a plausible way ahead in closing the gaps and seams that exist in the information network and physical network of the Joint theater distribution system between air and land components.

Detailing the Problem

The literature addressing Joint theater distribution is extensive. It includes works on the establishment and processes of a distribution system, Joint and Service doctrine, research articles, after action reports, briefings on the shortfalls of the current execution of the Joint distribution system, the command, and control of Joint theater logistics, and optimization of a specific portion of the theater distribution system. Major works from organizations and authors such as RAND, the Government Accountability Office (GAO), Colonel Fontenot, in *On Point*, *V Corps as Multi-National Corps – Iraq,* and the Joint Chiefs of Staff in their *Joint Distribution Deployment Enterprise* concept paper; all identify problems with the distribution system. Of the many problems identified, several deal with the air and ground interaction. In-theater experiences and observations identified the largest seams in the theater distribution systems. The seams highlighted in the interviews were the air and surface theater boundary, lack of common systems for managing requirements and capabilities, managing of modes separately, the point of interaction between aerial ports and the movement control team (MCT) and arrival/departure airfield control group (A/DACG), and finally, the managing of priorities for movement. While the creation of the JDDOC addressed some of these problems, several other problems require attention. In *Mending a Seam: Joint Theater Logistics,* several historical examples outline the continuing problems with Joint theater distribution and the capability to get large quantities of material to the theater of operations, but an inability to move that material forward.[4] In 2003, the GAO issued a report describing Department of Defense (DoD) distribution in Operation Iraqi Freedom as inefficient and ineffective.[5] Of the multitude of problems identified in the report, United States Central Command (USCENTCOM), United States Transportation Command (USTRANSCOM), and Defense Logistics Agency could only provide fixes to a few, such as cargo arriving in-theater and requiring repackaging for forward movement. Pure pallets reduced repackaging by shipping complete pallets from the depot to the end user.[6] The GAO also identified the problems that DoD—and specifically USTRANSCOM—encountered with obtaining information systems that communicate with each other to provide intransit visibility (ITV) and asset visibility.[7]

Several authors address the systematic problem the DoD has continued to experience since the Korean War: the transition from intertheater lift to intratheater movement.[8] Inability to smoothly transition from intertheater to intratheater movement creates backlogs at ports and delays the arrival of badly needed

resources to frontline units. To improve some of these areas, the Joint community is working to update Joint distribution doctrine. The doctrine requires updating to capture the considerable changes to the Joint distribution system since early 2003. The draft update to Joint Publication 4-09, *Global Distribution*, incorporates changes such as the JDDOCs, located on the combatant commander's staff to replace the function of the Joint Movement Center. The capstone logistics doctrine, Joint Publication 4-0, update will reflect several of the changes as well.

Doctrine presents several ways for the geographic combatant commander (GCC) to support theater distribution. One way to support theater distribution would be for the GCC to direct the most capable Service to provide the required capabilities and assets.[9] Under this arrangement, the GCC usually delegates operational control (OPCON) of other Service assets to the most capable Service.[10] Joint Publication 4-01.3, *Joint Tactics, Techniques, and Procedures for Joint Theater Distribution,* identifies two positive aspects of the most capable Service concept as "it satisfies requirements at the lowest level possible, and it frees the geographic combatant commander to focus on theater-wide critical issues."[11] Unfortunately, using the most-capable-Service concept does not support a seamless distribution system. The arrangement creates disconnects between air and surface movement because the most capable Services are different. The Air Force provides the most capability to command and control airlift and the Army provides the most capability to command and control ground lift. In very few circumstances would this division not be the case. To create an integrated distribution system, Joint Publication 4-01.3 recommends assigning responsibility to the Joint Movement Center, recently replaced by the JDDOC.[12] The selection of the best method for supporting the Joint team is also difficult because the Services have different concepts of support.

The Services have major differences in concepts of support and the command and control of the support forces, which include the Air Force's concept of agile combat support, the Navy's Sea Based Logistics, and the Army's Modular Force Logistics Concept. These different concepts of support, infrastructure, and force structure that the Services have developed to support them ensure that any solution to distribution problems must address these organizational structures. For example, the design of brigade support battalions (BSB) and logistics readiness squadrons (LRS) supports only their assigned brigade or wing. The BSB or LRS requires significant increases in resources if a Joint force commander (JFC) plans to increase these units' responsibility for supporting other forces. Additionally, the brigade and wing commanders have trained and planned with OPCON of the BSB or LRS, so command and control of these units at the brigade and wing levels must remain intact to ensure effective combat operations.

According to Joint doctrine, the geographic combatant commander (GCC), Service component staffs, and Service component operational units are required to run the theater distribution system and must link together for the system to work.[13] The Air Force was designated the lead Service for common user airlift and the Army was designated the lead Service for common user ground transportation, but no Service has responsibility for integration of the two modes. The designation of USTRANSCOM as the distribution process owner (DPO) and the creation of the JDDOC were a starting point; however, an organization with command and control authority is needed to bridge the gap. The JDDOC derives its authority from the JFC as a part of his Joint

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technology system for the management of the distribution system, as a single process for requesting movement and monitoring available capability, would dramatically improve an integrated organization's capability to manage the distribution system. The ability to compare all available capabilities and all requirements immediately is key to making good mode decisions in the distribution system.

Distribution system management should occur under a single manager, when possible, to reduce the impact of the natural seams caused by switching between modes.

Article Acronyms

A/DACG – Arrival/Departure Airfield Control Group
AMD – Air Mobility Division
APOD – Aerial Port of Debarkation
BCS3 – Battle Command Sustainment Support System
BSB – Brigade Support Battalion
CJTF – Commander Joint Task Force
CTC – Cargo Transfer Company
DPO – Distribution Process Owner
ESC – Expeditionary Support Command
FWD – Forward
GAO – Government Accountability Office
GCC – Geographic Combatant Commander
IT – Information Technology
ITARS – Intratheater Airlift Request System
ITV – Intransit Visibility
JDDOC – Joint Deployment Distribution Operations Center
JFC – Joint Force Commander
JFSCC – Joint Force Support Component Commander
JOPES – Joint Operational Planning and Execution System
JTF – Joint Task Force
JTF-PO – Joint Task Force-Port Opening
MCB – Movement Control Battalion
MCT – Movement Control Team
TSC – Theater Sustainment Command
USA – United States Army
USCENTCOM – United States Central Command
USJFCOM – United States Joint Forces Command
USMC – United States Marine Corps
USPACOM – United States Pacific Command
USTRANSCOM United States Transportation Command

Logistics Directorate but does not have command authority over any forces. The Joint community created Joint Task Force-Port Opening (JTF-PO) to solve the initial short-term problem of opening a Joint theater distribution network. However, JTF-PO does not support beyond 60 days for the sustainment of the Joint theater distribution network.[14]

The most recent draft Joint publication on global distribution calls for an end-to-end distribution system run as a Joint enterprise with sufficient authority to control the flow of materiel and personnel through the distribution pipeline.[15] Currently, only portions of the distribution pipeline run as Joint enterprises. These sections are the ones controlled by USTRANSCOM. In a theater of operations below the Joint task force (JTF) staff level, there are no Joint organizations to reduce the seams in the theater distribution system. So even though the GCC has the authority to control the flow of materiel and personnel through the distribution system, the lack of operational coordination between air and surface components and integration of Service tactical distribution units hampers the GCC's ability to seamlessly control the flow.

Many of the problems with Joint theater logistics stems from the ad hoc nature of the organizations identified to coordinate and control Joint theater logistics.[16] Army and Joint doctrine recognize that ad hoc organizations are required for logistics to operate in a theater of operations. These ad hoc organizations operate at the operational and tactical levels. In Afghanistan, an ad hoc Joint logistics command managed logistics for forces in country.[17] Throughout the USCENTCOM area of responsibility, A/DACGs operate as ad hoc organizations according to Field Manual Interim 4-93.2.[18] There are multiple ad hoc organizations in the USCENTCOM area of operations. Besides the A/DACG, forces in Afghanistan operated with a Joint logistics command and Joint movement control battalion. In Iraq, a Joint distribution center managed the distribution processes. These ad hoc organizations suggest the requirement for standing Joint units to meet the ongoing and future requirements. The Joint force support component commander (JFSCC) concept attempts to address this ad hoc nature of organizations at the operational level.

US Joint Forces Command (USJFCOM) in their Joint Experiment Distribution system covers the Joint Force Support Component Command (JFSCC) and other organizational options. USJFCOM identified that a major push for strategic and operational commands occurred because of the Services' failure to address seams in the distribution system, but an equal push to address the seams at the tactical level has not occurred.[19] Additionally, the creation of the JFSCC does not resolve the central problem—lack of visibility of capabilities and requirements. Only changes to processes and information technology can correct these deficiencies completely.

The processes that are central to distribution occur in the multiple organizations. In general terms, the organizations can be described as execution units and management units. The execution units handle personnel and cargo as they move through the Joint theater distribution system. Most of these units participate in terminal or port operations, or are the airlift squadrons or truck companies executing the movement. Joint Publication 4-01.5 outlines terminal processes as follows:

> Terminal operations involve receiving, processing, and staging passengers. It also includes receiving, loading, transferring between modes, and discharging unit and nonunit equipment and cargo. The main activities executed at terminals are loading and unloading modes of transport, marshalling, manifesting, stow planning, and documenting movement through the terminal.[20]

The MCB and JDDOC are management units that integrate the actions of the execution units to smooth the flow of personnel and materiel in the theater distribution system. The processes that they execute are movement control and distribution management.

In the air to surface interface of the distribution system, terminals are the key nodes.[21] These key nodes, when linked by transportation modes with the right personnel, material-handling equipment, and ITV systems, are the transportation structure in the distribution system.[22] Changes in the mode of transportation create the most visible seams. Every time a passenger or cargo passes between modes of transportation, there is a seam in the transportation system.

The Service organizations create seams in the system at their intersection because of different chains of command. Besides the natural seams between Services, the relationship between organizations in the system creates seams. The interviews raised concerns about the separation between the modes of transportation and the division of responsibilities of the theater distribution system between Services. The command and control relationships that exist according to doctrine for the theater distribution system are different from the command and control relationships executed in the United States Pacific Command (USPACOM) and USCENTCOM.

USPACOM and USCENTCOM do not have any theater ground capability integrated into the JDDOC. All the responsibilities for the ground movement are located in the Army component command. Without the capability to execute complete movement control through all modes of transportation, the JDDOC's effectiveness is hampered with regard to management of the complete theater distribution system. For example, in USCENTCOM the Theater Sustainment Command (TSC) sets and executes the priorities for ground movement and the CENTCOM Deployment Distribution Operations Center sets and executes the priorities for air movement. While the JFC has overarching priorities, the day-to-day execution of these priorities is not linked through unity of command and effort due to the seam created by the division of organizational responsibilities for management of the theater distribution system. This division highlights the problem of using the most capable Service to manage only portions of the Joint theater distribution system.

Service organizations create seams as cargo or passengers pass between organizations from different Services. At the operational level, validated requirements pass between the Services and the JFC, and then back to the Services for execution of the requirement. Seams have developed because of different processes and systems being used for managing requirements and capabilities for a mode. A large seam occurs during the transfer between JTF-PO and the Service organizations that must execute the long-term mission. The limited period for the JTF-PO to provide support at the deployed location creates a problem for the GCC for operations that last longer than the JTF-PO deployment period. The follow-on organizations do not fall under the same chain of command as the JTF-PO and are not

integrated into a single organization with a single command. For example the command and control for the Joint aerial port complex, which under JTF-PO has a single commander, reverts to a two-command system, as highlighted in Joint doctrine. The divided command and control for an aerial port of embarkation starts with the Air Force component having responsibility for the ready line and loading ramp area, the Air Force and United States Marine Corps (USMC) or United States Army (USA) components sharing responsibility for the call forward area, and the USMC or USA components operating the alert holding area and marshalling areas.[23] For an aerial port of debarkation (APOD), the Air Force operates the off-loading ramp area. The holding area responsibilities are split between Air Force forces and USMC or USA forces. The USMC and USA forces control the marshalling area. Doctrine acknowledges the difficulty of operating in this two-command system in a single process.[24] The USMC and USA further complicate the process by making one of the key organizations, the A/DACG, an ad hoc organization. Army doctrine, while highlighting the ad hoc nature of the A/DACG organization, does state that the organization should be composed of cargo transfer company personnel.[25]

To bridge the natural seams that exist in any distribution system, the Joint community and Services developed several organizations. The multitude of organizations created overlaps the command and control issues. For the Joint theater distribution to meet the objectives of the JFC, the organizations that manage and execute the system must provide the capability to coordinate and synchronize the multiple facets of the system with unity of effort. Most of the overlaps in capabilities exist so each Service does not have to depend on another Service to provide the common user logistics capability. The overlaps between the various organizations with the capability to provide common user support indicate areas where possible integration of units may exist. The integration could be in the form of training, organization, operating instructions, or doctrine. The TSC and JDDOC have overlap in roles and responsibilities as defined by their concepts. The major area of overlap is the capability to coordinate with USTRANSCOM representatives and integrate distribution across the modes of transportation. The overlap of responsibilities has created different documents for requesting transportation support.

The current processes reflected in the transportation request process and command and control are not conducive to supporting the principles of theater distribution—specifically, centralized management and continuous, seamless, two-way flow of resources. There are multiple systems used to identify movement requirements with the Services using multiple processes to identify the movement requirements. The Air Movement Request, Transportation Movement Request, and Joint Movement Request are one set of processes for supporting the identification of requirements. In addition to using multiple systems to identify movement requirements, the Services and Joint community use multiple systems to identify the movement capabilities available. These multiple systems create a lack of integration in the management of movement requests as identified in our interviews. In general, the idea of combining the multiple forms into a single process received positive responses from the interviewees. To highlight the utility of the single requirements system, the interview responses reflected a desire for a single ticket process for the shipper. The single ticket process allows cargo or passengers to receive end-to-end scheduling of transportation without the need for additional transportation requests as modes of transportation change. The capability for intermodal management was a primary reason identified for combining the forms. Additionally, the interviewees agreed that the capability to receive a requirement and centrally manage the best mode for that movement was highly beneficial. However, most felt that without the single process owner merging the request forms, they would be ineffective because of the lack of command and control for the requirements.

All ten of the general officers and colonels interviewed supported the management of requirements by one theater organization. They felt consolidation was a positive development for the theater distribution, which, given the proper information technology (IT) capability and a well-defined command and control structure, could be successful. The major concerns expressed were as follows.

- Maintaining the capability of the tactical commander to weigh efforts for lift assets above the echelon supporting his unit
- Lack of IT to make the organization successful
- The ability of Services to maintain assets for their internal support

Data analysis confirmed that the creation of a single structure for the management of requirements, combined with a reduction in the multiple processes and information systems (which hamper the effective and efficient use of the distribution system) could greatly improve the performance of the Joint theater distribution system.

The data analysis further supports that a single organization, given the correct responsibilities and tools, can improve the management of the theater distribution system to meet mission requirements. A comparison of movement data for city pairs during the first 20 days in August 2006 and August 2007 gave a basic picture of a change the MCB made with the handling of cargo for movement between locations in Iraq. A city pair was a match between a mode originating location and a mode destination. Changes made between 2006 and 2007 created a more integrated system to take advantage of space available on aircraft moving between locations in Iraq. One notable change included air marshalling yards controlled by MCTs for cargo that had a long lead time for its required delivery data, and could move via air or ground.[26] This change allowed the MCTs to pick the best way to move the cargo based on requirement, threat, and available assets. While not an entirely Joint approach, the MCTs could not have started this process without the support of the Air Force aerial ports. This change in the handling of cargo played a role in the reduction of air and ground missions in Iraq 1 year later. The reduction occurred even with an increase in the number of combat troops by at least 21,000 in 2007 over 2006,[27] and the number of locations with air missions increasing from 20 locations in 2006 to 23 locations in 2007.

The management of the different modes of transportation in the distribution system by different organizations, tied with the lack of a common IT system to gather and share requirements and capabilities, proved to be the largest seams in the distribution system. In addition to the divided management of requirements

and capabilities, the interviews raised concerns about divided execution at the seams between Service organizations such as the aerial port and A/DACG. The interview responses showed concern with the integration of the distribution system between modes and organizations. They felt the entire system lacked personnel with the required training so prioritization within the system was a problem. The lack of training and poor visibility of the requirements and capabilities in the system also prevented the echeloning of capability to allow for a prioritization and tasking at lower levels. Additionally, the interviewee felt that the lack of training for personnel executing the distribution created a large negative impact on the system and the modes of the distribution system. The individuals were unable to execute the system effectively and efficiently because they did not have the knowledge required to do so.

The following conclusions and recommendations were derived from literature review, interviews, and data analysis. They provide one path to improved performance of the distribution system. One item of interest from the responses received is the lack of a common understanding of what comprises the theater distribution system. This problem highlights the need for increased Joint training on the operation of the Joint theater distribution system starting at the lowest levels.

Conclusions

The normal seams that one would expect to find were identified by the literature review and the interview analysis. These traditional seams included locations where cargo or personnel change modes of transportation, and at the organizations that operate these nodes in the distribution system. The interviews and literature also identified additional seams at areas where information systems do not exchange data. Finally, the exchange between intertheater and intratheater transportation management and execution created the most significant seam in the distribution system because of cargo and personnel change modes, information systems, and organizational management. Doctrine provided additional insights into the Joint theater distribution system.

Doctrine provides a wide range of views on the organization and management of the Joint theater distribution system. Joint doctrine provides an overarching view of the strategic, GCC, and the JTF levels of command and management for the Joint theater distribution system. However, portions of the operational, and most of the tactical, levels of the theater distribution system are divided by Service doctrine. The division inhibits the capability of the system to operate seamlessly by creating gaps between tactical and operational level distribution perception and operation. This is especially troublesome when a Service makes assumptions about the capability of another Service to support a multimodal location such as an aerial port. Movement control doctrine in general does not address how the various forces work together to bridge the seams.

After action reports, RAND, doctrine, and interviews provided detailed insight into the organizations of the current distribution system. These sources identified that the integration of the organizations in the theater distribution system must occur. Additionally, they provided multiple views on how the integration should occur at the operational level of logistics, ranging from a single JFSCC to executing doctrine as written for the JDDOC. At the tactical level, these same sources suggest integration of the organizations that operate multimodal hubs at the Joint aerial port complex and Joint Theater Distribution Center. Some authors suggested an increase in Joint training of the current organizations that operate in those environments and the merging of the Service organizations into Joint organizations to decrease the size of the seam that occurs between air and ground at these points in the distribution system. The Services have integrated their internal distribution systems, whether it is the TSC Distribution Management Center, the Air Force's LRS or Global Logistics Support Center, or USMC's Marine Logistics Group. The strength of these units to respond and provide logistics support for both their own Services and a common user logistics environment show the strength of integrated logistics. Our analysis showed the Joint community beyond the DPO has failed to integrate Joint theater distribution under a single commander or organization. The distribution system management should occur under a single manager, when possible, to reduce the impact of the natural seams caused by switching between modes.

A single command structure responsible for the movement control of the theater could better utilize available assets to meet mission requirements by selecting the mode that would be most effective for the mission. The data analysis indicated that a single Joint theater distribution, operating with true unity of effort in the management of the system, could meet the objectives of the JFC—in this case, the reduction of the number of convoys conducted. For example, minimum requirements for the use of a C-130 prevent organizations from submitting cargo for air transportation, but a single organization responsible for mode selection could make decisions based on availability of all assets above echelon to use a C-130 for the movement of less than the normal requirement for use of a C-130. The single organization could also reroute cargo to an Army sherpa designated for above echelon support to meet the requirement. These decisions made by a single organization would require changes to the processes for management of the system.

Changes to the processes currently used for the management of the Joint theater distribution system need to occur. Analysis of the interviews concluded that a single or integrated IT system for the management of the distribution system, as a single process for requesting movement and monitoring available capability, would dramatically improve an integrated organization's capability to manage the distribution system. The ability to compare all available capabilities and all requirements immediately is key to making good mode decisions in the distribution system. The work USTRANSCOM is conducting on information systems, if supported by the Services, could quickly fix the asset visibility problems.

Recommendations

A single organization responsible for consolidating requirements and committing the Services' capabilities in accordance with Joint doctrine organizations (such as the Joint movement control center) would increase the flexibility of the GCC and JTF commanders to meet movement requirements with the best mode of transportation. The JDDOC provides the capability to execute this organization, if Army personnel dealing with ground

transportation requirements are assigned to the surface cell of the JDDOC. The requirement for a forward JDDOC element stationed with the JTF could meet the need for an organization familiar with local requirements to validate, prioritize, and forward requirements to the Service for execution. The forward element would coordinate all intratheater movement requirements, with the main JDDOC responsible for integration of intertheater movement within the theater distribution system.

Consolidation of cargo yards for ground and air distribution would allow maximum flexibility for transfer between modes and a single authority controlling mode selection ensures the most effective and efficient use of available transportation assets based on the priority of the JFC. Instead of cargo being placed in the aerial port marshalling yard, or in the ground marshalling yard, the cargo should be placed in a general marshalling yard until the mode is decided based on availability of resources, priority, threat, and timing, and then moved to the correct mode for final preparation and Joint inspection. These yards should be collocated for enhanced communication between mode operators.

Management, Organizational, and Process Changes

The organizational structure and division of responsibilities recommended below are in agreement with RAND's most recent publication dealing with the Joint multimodal distribution system.[28] The JDDOC provides the capability necessary to manage the theater distribution system, if properly staffed and resourced according to doctrine. The TSC must give up its capability to manage ground requirements to the JDDOC so that the management of all modes of transportation in the distribution system can be integrated across all Services and at all levels. To integrate across all levels, the JDDOC must utilize the JDDOC forward (FWD) capability to support JTFs for the GCC.

The JDDOC should also change from a center to a command organization for the management of the requirements in a theater distribution system. To provide capability to the lowest levels, MCBs should be assigned to the JDDOC. MCBs provide the management capability required to manage the theater distribution system if they become Joint organizations. Our research has shown that in the current conflict, many MCBs have Air Force liaison officers embedded within the organizations. Instead of making this organization an ad hoc organization, the MCBs should re-flag as Joint organizations and transfer from Army ownership to direct reporting units to the JDDOC at USTRANSCOM. The units should remain at their current home stations for training purposes and for development of the necessary relationships with Expeditionary Support Command (ESC) and sustainment brigades. Additionally, the command relationship with units deployed in an MCB's area of operations should be one of direct support, the same relationship that exists today. MCBs, when deployed, should receive operational command and control from the JDDOC FWD, providing theater management capability from top to the bottom. Each MCB should provide direct support to an ESC or sustainment brigade, depending on the size of the deployment. The MCT relationship should remain as it is today. This organizational structure provides an honest broker capability at all echelons of distribution. The MCBs can maintain their current structure with the addition of Joint personnel with specific Service capabilities for the management of the system. Figure 1 outlines the organizational relationship for the management and execution of the Joint theater distribution. There would be no change in the command relationships for Army organizations as identified in current doctrine and organizational relationships. This figure also represents the execution side of the theater distribution system with the TSC, ESC, and sustainment brigades. These organizations have the responsibility to execute the identified transportation requirements in coordination with the management portion of the theater distribution system.

The Air Force command relationships identified in Figure 1 show no change from current doctrine. The Air Force forces component has OPCON over all assigned Air Force forces and the Joint force air component commander (JFACC) has tactical control (TACON) over those forces provided. The air mobility division (AMD) as the JFACC's airlift controlling authority has a TACON relationship with the air terminal operations center through the layers of command. The Air Force command relationships are for the air execution portion of the distribution system.

The recommendations for changes in the Joint theater distribution system are to the management organizations and their command relationships with each other, and with the execution portion of the theater distribution system. The change of the MCB to a Joint organization assigned in an OPCON relationship with the JDDOC creates a single organization for the management of the theater distribution system at the operational and tactical levels of command. In addition to this change, the TSC and AMD should have direct support relationships with the JDDOC. The JDDOC, through the MCBs and MCTs, should have direct support relationships to the various levels of the execution portion of the distribution system. The direct support relationship of the TSC and AMD to the JDDOC allows the JDDOC to provide management of the execution of the movement requirements and priorities. The JDDOC, as a command organization, must reorganize its structure from a mode driven structure to an operational structure with a current and future operations cell. The manpower for the Joint manning document of the organization exists currently with the exception of the theater ground piece. These manpower billets currently reside in the TSC and ESC. The management portion of these billets (those that handle requirements, allocation, and commitment) should be moved to the JDDOC with the TSC and ESC retaining the billets to execute the ground transportation system. The JDDOC FWD provides the commander Joint task force (CJTF) a direct element into the Joint theater distribution system. The JDDOC FWD, while assigned to the JDDOC, provides direct support to the CJTF. The JDDOC FWD also has OPCON over MCBs assigned in its area of responsibility. The JDDOC retains its current alignment assigned to the GCC. Figure 1 outlines these command relationships.

The removal of the theater designation of what can and cannot move via air would give the flexibility to the movement control organization to use all the modes of transportation available to meet the JFC priorities. The processes necessary for the management of the movement control system at all levels include properly identifying requirements and providing visibility on modal decisions to all organizational levels.

An overarching description of the proposed request and execution systems provides insights into the streamlined nature

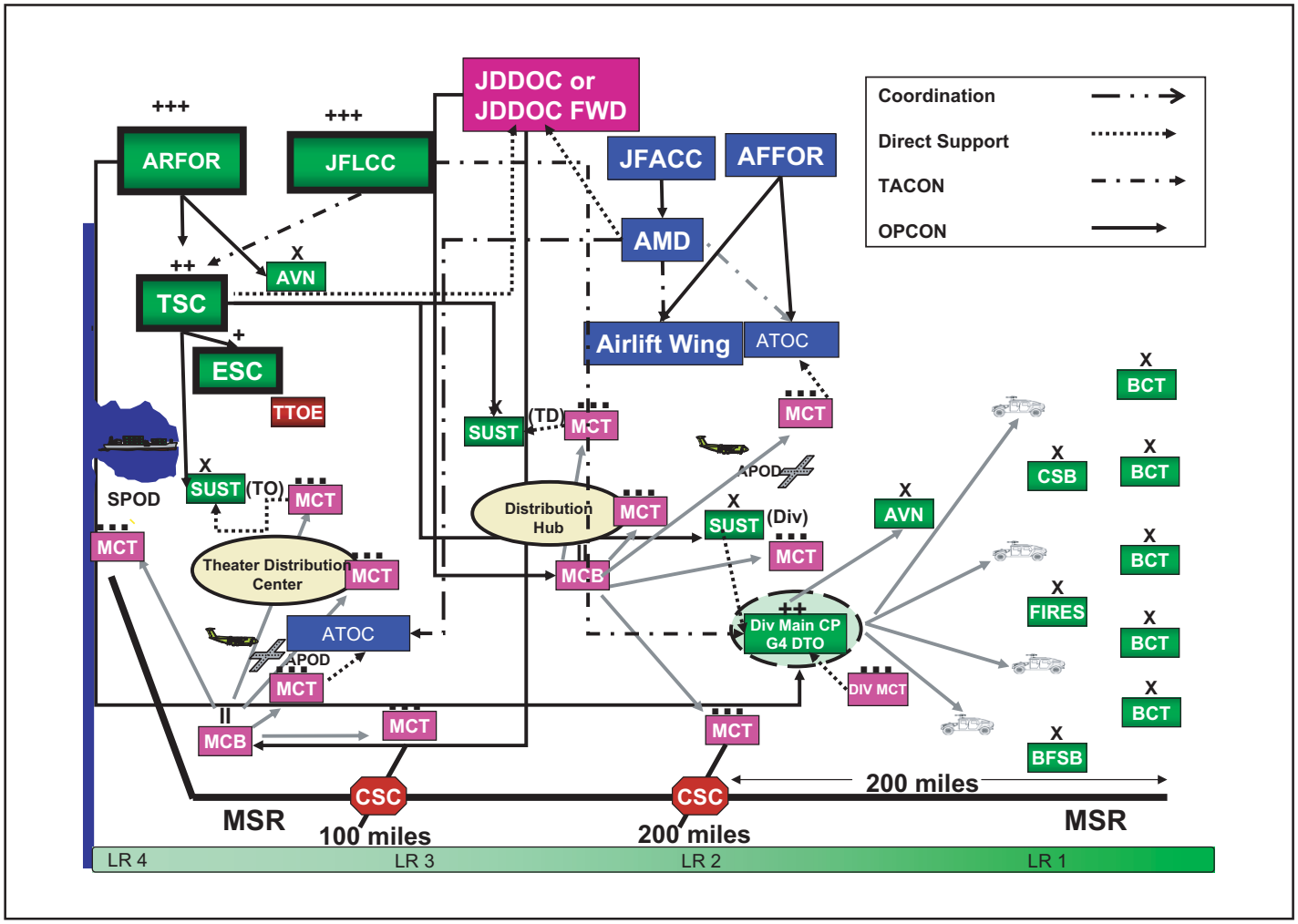

Figure 1. Recommended Organizational Relationships[29]

required to operate a Joint theater distribution system. Starting at the beginning with requirements definition outside of division capabilities (lower right of Figure 2), the division staff coordinates its movement requirements with the Corps Staff in the event that the division MCT does not have the assets available to it for commitment. The MCT forwards the request to the area MCT, normally collocated with a sustainment brigade, for support. The MCT with a support relationship to the sustainment brigade has the ability to commit its transportation assets and provide support to other MCTs in its area of operation. Requests for transportation that are above the MCT's capacity should be forwarded to the MCB for routing to other MCTs for support, or forwarded to the JDDOC FWD. At the division level, the aviation unit assigned to the division can identify assets for the division MCT to commit for movement requests. MCTs can also push cargo to Army aviation units for movement on previously scheduled airlift missions or regularly scheduled lift missions (channel missions) for space available movements. For successful use of channel missions, the MCTs require visibility over all cargo requiring movement at the aerial port so the Joint MCT can better prioritize all cargo for air movement—not just Army cargo.

One area not represented in the figure is the continuous coordination between MCTs. Movement requirements are not all met with formal movement requests, as shown in Figure 2. Some requirements are met by pushing smaller amounts of cargo to a port or terminal for movement on air channel missions or on a space available basis.

Above the division level, the Army Forces Component may designate some aviation assets to support the distribution system. The JDDOC FWD should have responsibility for managing these resources in the same manner as Air Force lift assets. If an MCB cannot support a request from one of its MCTs, the request moves to the JDDOC FWD. The JDDOC FWD reviews and validates the request and forwards the request to the appropriate mode for execution through either the AMD or the ESC. If the JDDOC FWD does not have the assets available for commitment, the request is forwarded to the JDDOC. If the JDDOC determines that ground movement will best support the requirement, the commitment is sent to the TSC. If it determines that airlift best supports the requirement, the commitment is sent to the AMD or to USTRANSCOM for support.

With the management of the request process conducted by a single command and control structure with Joint capabilities, the Services can concentrate on meeting the requirements given to them to execute. Additionally, the parochial concerns of the Services about the fairness of a system managed by one Service or another can be overcome. The changes also ensure that the tactical units are able to influence the Joint theater distribution system to the level they require to meet their requirements, as

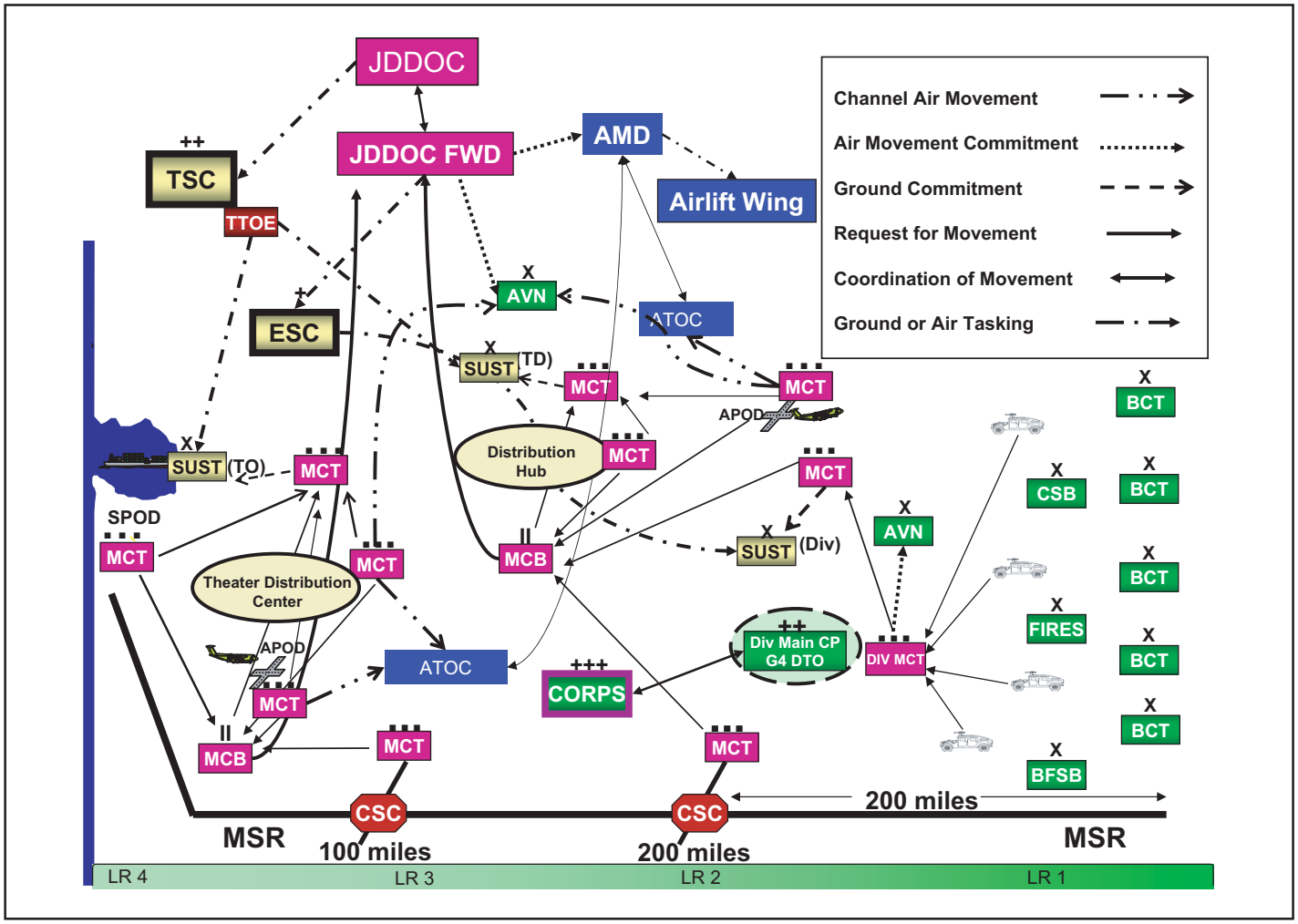

Figure 2. Recommended Joint Movement Request Process[30]

well as the GCC and JTF priorities. The current system's failure to address the tactical commander's concern for airlift due to GCC imposed priorities and limited tactical level system management capabilities creates friction between tactical and operational objectives. Placing management of the system under a single chain of command for unity of effort—with well-defined support relationships of that management system—addresses these concerns.

Execution, Organization, and Process Change

The execution organizations from the Services require little change, with the exception of the Joint aerial port complex. To improve the flow of cargo through the Joint aerial port complex, the A/DACG must cease to be an ad hoc organization. The Army must assign this responsibility to one of the cargo transfer company's platoons or entire cargo transfer companies (CTC), as necessary. To improve execution of the system, these CTCs should be collocated and teamed with Air Force units for training purposes at locations such as McChord Air Force Base and Ft Lewis, Washington. In addition, the Joint movement control teams should be further integrated into the training of the Joint aerial port complex so a single set of instructions can be developed for the execution of aerial port activities and reduce the seam created by personnel in an ad hoc organization unfamiliar with the aerial port system.

The Joint community should seek to link existing aerial port squadrons and logistics readiness squadrons with existing movement control battalions and cargo transfer companies for training and experience exchange, especially at locations with collocated Army and Air Force units. This enhanced training would greatly increase the capability of units to function as a team in-theater when they move to replace JTF-PO for sustainment operations at the APOD or intratheater terminals and increase the number of units capable of providing JTF-PO type functions. If Services are unwilling to integrate training and positioning of forces as ready tailored teams to meet the needs of the GCC, the Air Force should explore training the Air Force Traffic Management career field personnel to carry out the MCT port clearing duties. The training of traffic management airmen to execute these responsibilities would create a team capable of meeting the need to integrate theater ground and air within a single tactical organization at the aerial port.

Information Technology Systems

USTRANSCOM's Theater Enterprise Deployment Distribution project identifies the gaps in IT systems. This USTRANSCOM project must be successful at providing one-stop shopping for the planner to see all requirements and all capabilities including ITV to allow for dynamic rerouting of theater capabilities and requirements. The effort should consolidate the Intratheater Airlift Request System (ITARS), Global Air Transportation

Execution System (GATES), Cargo Movement Operations System (CMOS), Transportation Coordinator's Automated Information for Movement System II, Battle Command Sustainment Support System (BCS3), and Transportation Logistics (TRANSLOG) Web data to provide complete requirements to the distribution planner and user. While not discussed in detail in this article (because it often involves intertheater movement), the data for movement requirements from the Joint Operational Planning and Execution System (JOPES) should be incorporated into the system, because the deployment and redeployment of forces places large requirements on theater distribution. The combined system should also pull the data from JOPES for deployment and redeployment requirements. Additionally, ITV systems for ground (MCT, BCS3) and air must be incorporated into the structure. In the short term, the combining of ITARS and TRANSLOG Web to create a single system for requesting lift would increase visibility of all requirements and aid in the management of the current organizational structures.

The ad hoc nature of the processes and organizations in current doctrine and theater distribution—mainly along Service lines—creates a less than seamless theater distribution system. The result of failing to improve the theater distribution processes is the continued poor effectiveness and efficiency experienced during Operation Enduring Freedom and Operation Iraqi Freedom. The Services must overcome their parochialism toward Service capabilities and integrate these capabilities through information systems and integrated management of the system.

Notes

1. Colonel Gregory Fontenot (Retired), Lieutenant Colonel E. J. Degen, Lieutenant Colonel David Tohn, *On Point: The United States Army in Operation Iraqi Freedom,* Fort Leavenworth, KS: Combat Studies Institute Press, 2004, 408-409.
2. Robert S. Tripp, Kristin F. Lynch, Charles Robert Roll, John G. Drew, and Patrick Mills, *A Framework for Enhancing Airlift Planning and Execution Capabilities Within the Joint Expeditionary Movement System,* Santa Monica, CA: RAND Corporation, 2006, xx.
3. Tripp et al, xvii.
4. Lieutenant Gregory S. Otey, "Mending a Seam: Joint Theater Logistics," *Air Force Journal of Logistics,* XXX, No 2, 12.
5. U S Government Accounting Office (GAO), *Defense Logistics: Preliminary Observations on the Effectiveness of Logistics Activities during Operation Iraqi Freedom,* William M. Solis, GAO 04-305R, Defense Logistics, Washington, DC: Government Printing Office, 18 December 2003, 3-4.
6. U S Government Accounting Office (GAO), *DoD Has Begun to Improve Supply Distribution Operations, but Further Actions Are Needed to Sustain These Efforts,* William M. Solis, GAO 05-775, Supply Distribution Operations, Washington, DC: Government Printing Office, August 2005, i.
7. US Government Accounting Office, 2005, 5.
8. David J. Kolleda, *Developing the Theater Level Aerial Port of Debarkation, Organization and Structure,* Fort Leavenworth, KS: School of Advanced Military Studies, 23 April 1996, 30.
9. Joint Publication 4.01.3., *Joint Tactics, Techniques and Procedures for Movement Control*, Washington, DC: The Joint Staff, 9 April 2002, I-6.
10. Joint Publication 4.01.3., I-6 and I-7.
11. *Ibid.*
12. Joint Publication 4.01.3., III-1.
13. Joint Publication 4.01.4., *Joint Tactics, Techniques and Procedures for Joint Theater Distribution*, Washington, DC: The Joint Staff, 22 August 2000, IV-4–IV-5.
14. US Transportation Command, *Joint Task Force-Port Opening (Aerial Port of Debarkation) Concept of Operations,* Version 1.65, Scott Air Force Base, Illinois: Strategy, Policy, Programs and Logistics Directorate, DPO Program Management and Strategy Division,6 March 2007, 3.
15. Joint Publication 4.09., *Doctrine for Global Distribution (Draft),* Washington, DC: The Joint Staff, July 2007, III-15.
16. Mark E. Drake, *How to Improve Responsiveness for Theater Level Joint Command and Control Requirements*, Carlisle Barracks, PA: US Army War College, 21 February 2006 and Mark Brady, *Beans, Bullets and Black Oil … Are We Delighting the Joint Force Commander?* Newport, RI: Naval War College, 16 May 2003, 16.
17. David D. Dworak, *The Future of Joint Logistics: A Proposal for Achieving True Joint Logistics within the American Military*. Carlisle Barracks, PA: US Army War College, 15 March 2006, 7.
18. Field Manual Interim 4-93.2, *The Sustainment Brigade,* Final Draft, Washington, DC: Department of the Army, 4-37.
19. US Joint Forces Command, J9, *Joint Experimental Deployment and Support*, Norfolk, Virginia: Joint Concept Development and Experimentation Spotlight, October 2007, 1.
20. Joint Publication 4.01.5., *Joint Tactics, Techniques and Procedures for Transportation Terminal Operations,* Washington, DC: The Joint Staff, 9 April 2003, I-3.
21. Field Manual (FM) 4.0, *Combat Service Support,* Washington, DC: Department of the Army, 7 August 2003, 7-4.
22. *Ibid.*
23. Joint Publication 4.01.5., III-9.
24. Joint Publication 4.01.5., III-12.
25. Field Manual Interim 4-93.2, *The Sustainment Brigade,* Final Draft, Washington, DC: Department of the Army, 4-37.
26. Gust W. Pagonis, *Operational Distribution: Effectiveness versus Efficiency*, Newport, RI: Naval War College, 6 November 2007, 13.
27. House Armed Services Committee, Hearing of the House Armed Services Committee: The Way Forward in Iraq, Federal News Service, 11 January 2007, [Online] Available: http://web.lexis-nexis.com.lumen.cgsccarl.com/congcomp/document?_m=98716513758d6f26d5361cce2ce2b163&_docnum=2&wchp=dGLbVzW-zSkSA&_md5=5a19483e9bd9121ebc13eeb2febcca71, accessed 6 May 2008, 21.
28. John Drew, et al, *Applying the Strategies to Tasks Framework for Integrating Theater Airlift into the End-to-End Joint Multi-Modal Expeditionary Movement System*, Santa Monica, CA: RAND, 2008.
29. Force Development Directorate–Distribution, "Movement Control," Power Point Briefing. US Army Combined Arms Support Command, 1 February 2007, [Online] Available: https://forums.bcks.army.mil/secure/CommunityBrowser.aspx?id=329640, accessed 28 February 2008, 7.
30. *Ibid.*

***David A. Anderson**, DBA, is an associate professor in the Department of Joint, Interagency, and Multinational Operations, US Army Command and General Staff College, Fort Leavenworth, Kansas. He is a retired Marine Corps lieutenant colonel who served his entire career as a logistician in various tactical- through strategic-level staff and command positions.*

***Major Timothy W. Gillaspie** is currently the Commander, 375th Logistics Readiness Squadron, Scott Air Force Base, Illionis. At the time of writing this article, he was a student at the Army Command and General Staff College, Fort Leavenworth, Kansas.*

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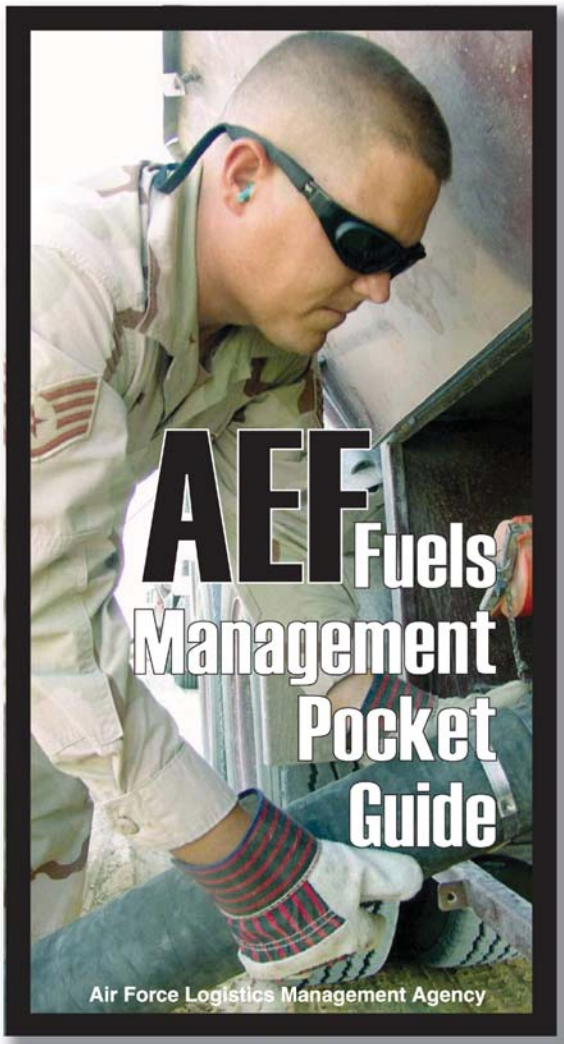

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Logistics Stuff—Five Things to Consider

- **The operations/logistics partnership is a target for our enemy—protect it.** We must try always to think of an enemy's 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/logistics partnership of the enemy is a target for us; we must attack it.
- **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.
- **Think about what needs to be done and 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. 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.
- **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.
- **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.

Group Captain David J. Foster, RAF

Challenges

21st Century Logistics

Transforming the Aircraft Inspection Process

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 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 Air Force Smart Operations for the 21st Century (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 program budget decision-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 Maintenance Steering Group-3 approach offers the Air Force an opportunity to fully exploit AFSO21 efficiencies to produce combat-ready aircraft with increased 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.

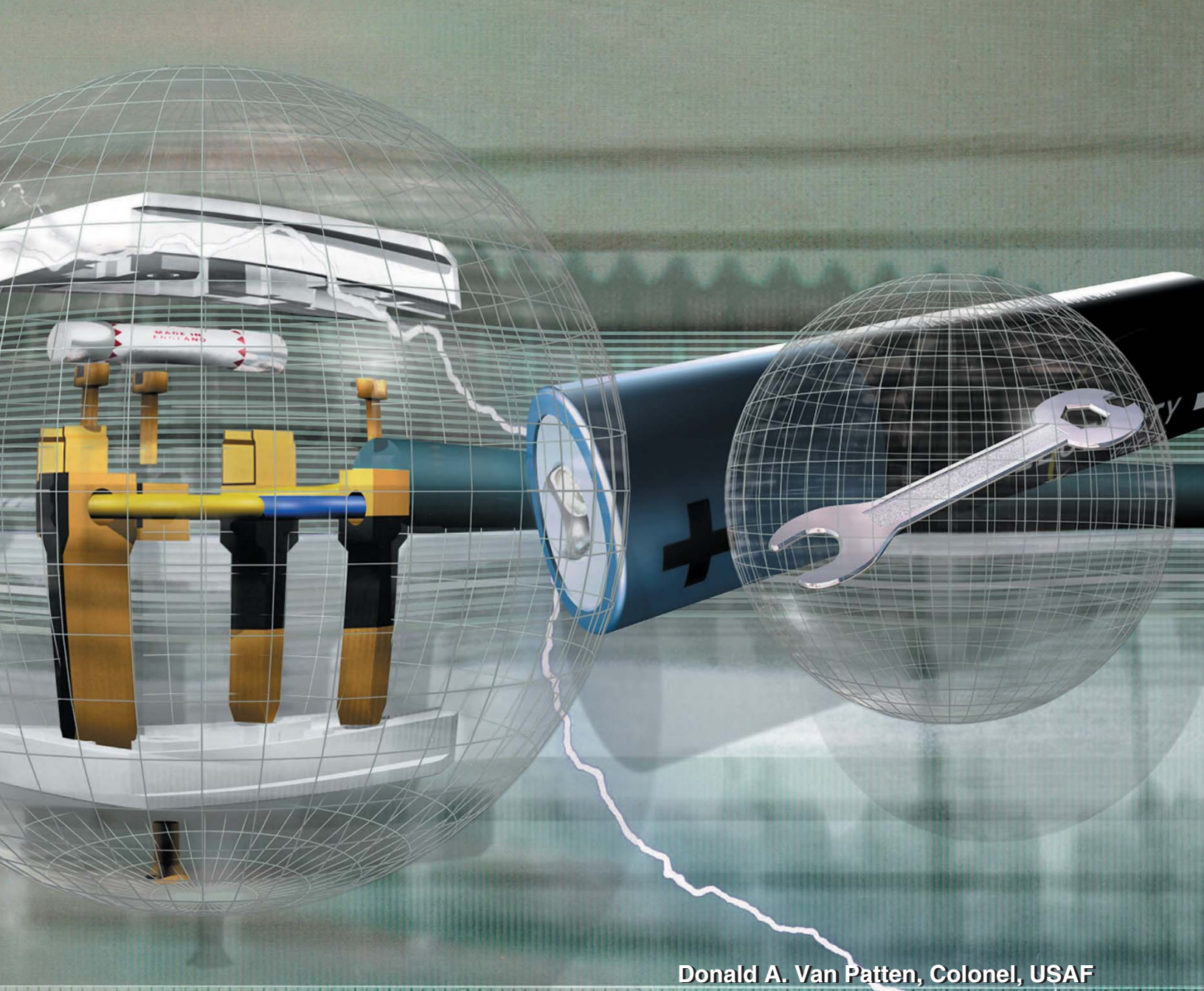
Transforming the Aircr

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



Donald A. Van Patten, Colonel, USAF

aft Inspection Process

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]

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

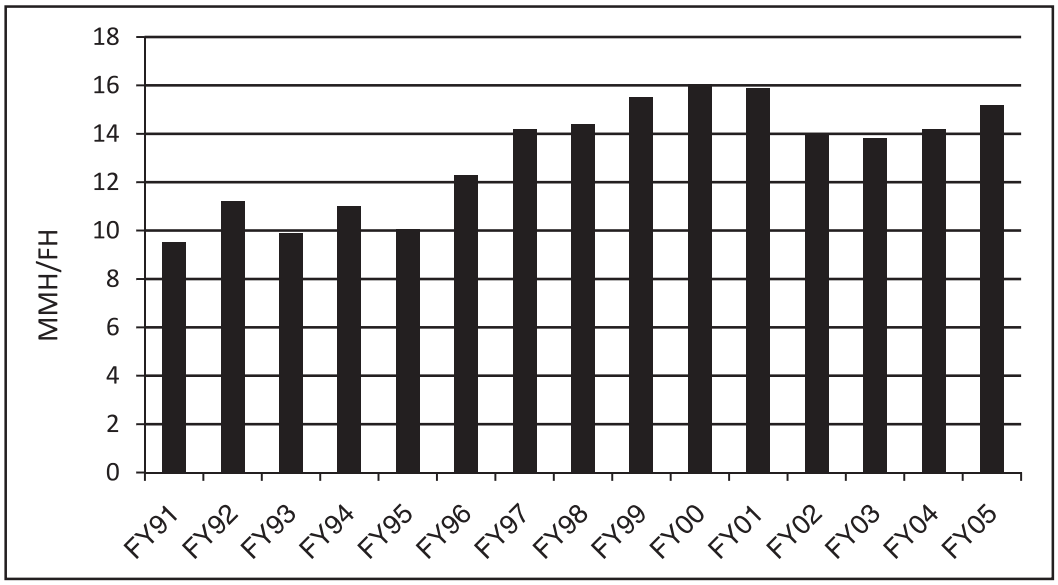


Figure 1. Total Air Force Maintenance Man-Hours per Flying Hour, FY91–FY05

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 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 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 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 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

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

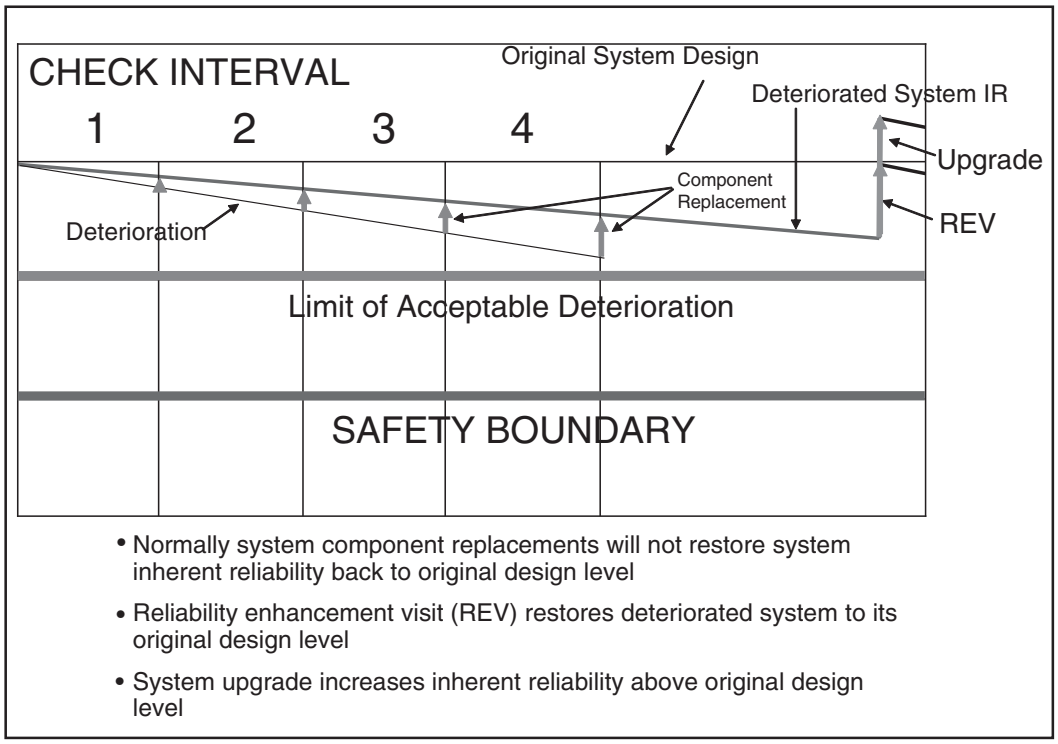


Figure 2. Predetermined Levels of System

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.

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 $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.

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

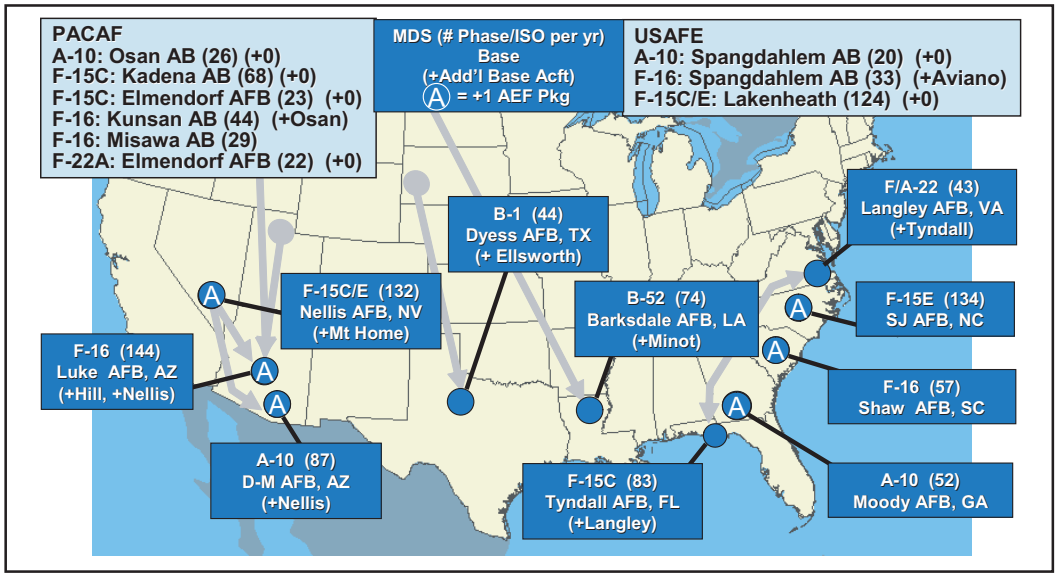


Figure 3. Option 2 Regional Inspection Concept—Combat Air Forces

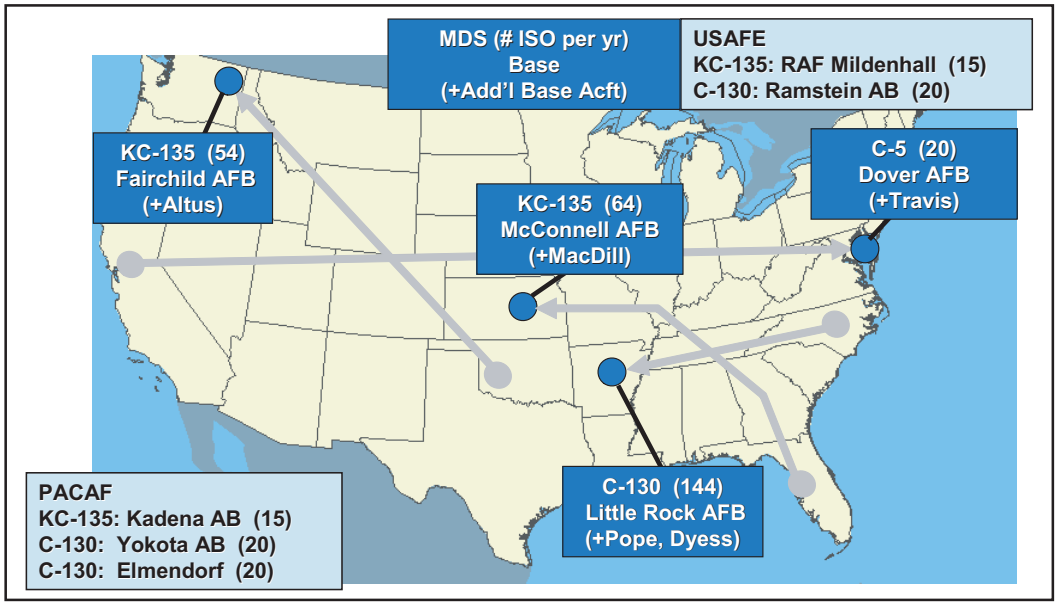


Figure 4. Option 2 Regional Inspection Concept—Mobility Air Forces

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.

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.

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

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] 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 chapter 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.

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 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

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

system degradation and formalize them in a revised minimum essential systems list (MESL) to balance mission 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]

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 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 December 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 December 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 April 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 August 2006 AAIP.
6. Col John Stankowski, Chief, Weapons System Division, HQ USAF/A4MY, Briefing, subject: eLog21 - AAIP, 1 December 2006, slides 3-25. The AAIP was formed in April 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.
8. Lt Gen Steve Wood, Director of Requirements, Headquarters USAF/A8, Subject: Blue Horizons, Briefing, 3 August 2006, Slide 22.
9. Headquarters USAF/A4MY, subject: What are the Effects of Aging?, 2 February 2006, slide 1.
10. Air Force Portal, Applications: Multi-Echelon Resource and Logistics Information Network (MERLIN), Mission Performance, MMH per FH for total Air Force inventory, FY91-FY05, [Online] Available: https://www.my.af.mil/merlinprod/MissionPerformance/mission_WSA_unit.asp, accessed 18 February 2007.
11. Lt Gen Wood, Blue Horizons, slide 23.
12. Department of Defense, *Operating and Support Cost-Estimating Guide,* Washington, DC: Office of the Secretary of Defense [Cost Analysis Improvement Group (CAIG)], May 1992, 4-1 to 4-8. The CAIG is an OSD body that analyzes merged data from the AFTOC, Reliability and Maintainability Information System (REMIS), Multi-Echelon Resource and Logistics Information Network (MERLIN), and Personnel Data System (PDS) systems. There are seven main CAIG-element categories of cost data contained in the AFTOC: mission personnel pay and allowances, unit-level consumption, intermediate maintenance, depot maintenance, contractor support, sustaining support, and indirect support.
13. Lt Gen Wood, Blue Horizons, slide 21.
14. Maj Gen Frank Faykes, Deputy Assistant Secretary for Budget (Financial Management and Comptroller), Headquarters SAF/FMB, subject: FY07 USAF Posture & Acquisition Hearing (HAC-D) briefing, 8 March 2006, slide 10.
15. *Webster's Third New International Dictionary of the English Language, Unabridged*, s.v. "isochronal."
16. Air Force Instruction (AFI) 21-101, *Aircraft and Equipment Maintenance Management*, 29 June 2006, 24-25.
17. Col Steve Schumacher, Chief, Weapons System Division, Headquarters USAF/A4MY, subject: "Cost To Sustain & Operate Select Aging Aircraft," briefing, 15 November 2005, slide 5.
18. Gen John Jumper, Chief of Staff (CSAF), Headquarters USAF, "Wing Organization Evolution, 1947-2002," briefing, 21 February 2003, slide 37.
19. AFI 21-101, *Aircraft and Equipment Maintenance Management*, 29 June 2006, 381.
20. Dave Nakata, "Why Transition to a MSG-3 Based Maintenance Schedule?," EmpowerMX White Paper, [Online] Available: http://www.empowermx.com/whitepapers/MSG3.pdf, accessed 12 December 2006.
21. F. Stanley Nowlan and Howard F. Heap, *Reliability-Centered Maintenance*, San Jose, CA:Dolby Access Press, 1978, 5-6.
22. Airline Transport Association (ATA) of America MSG-3, *Operator/Manufacturer Scheduled Maintenance Development*, Revision 2003,1,5.
    The ATA is the principle trade organization of major US airlines, OEMs, and other airline-related businesses.
23. Dave Nakata, "Why Transition to a MSG-3 Based Maintenance Schedule?" 1-2.
24. Nowlan and Heap, *Reliability-Centered Maintenance*, vii.
25. ATA of America MSG-3, *Operator/Manufacturer Scheduled Maintenance Development*, 4.
26. DoD MIL-STD 1629A, *Procedures for Performing a Failure Mode, Effects and Criticality Analysis*, 24 November 1980, iii.
27. *Ibid.*
28. Scott Vandersall, Chief Engineer (C-5), 730th Aircraft Sustainment Group (AFMC), "Maintenance Steering Group 3 (MSG-3)," briefing, 17 January 2006, slide 6.
29. ATA of America MSG-3, *Operator/Manufacturer Scheduled Maintenance Development*, 12.
30. ATA of America MSG-3, *Operator/Manufacturer Scheduled Maintenance Development,* 7-8.
31. Dr Edward Rogers and Col Robert P. Birmingham, USA, "A Ten-Year Review of the Vision for Transforming the Defense Acquisition System," *Defense Acquisition Review Journal*, January-April 2004, 38-40, [Online] Available: http://www.dau.mil/pubs/arq/2004arq/Rogers.pdf.
32. Discussion with Col Steve Schumacher, Chief, Weapons System Division, Headquarters USAF/A4MY, Pentagon, DC, 7 April 2006.
33. Colonel Schumacher, "Enterprise View of Aircraft Inspections," briefing, slides 36-37.
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.
35. Technical Order (TO) 1F-15A-6WC-5, *Workcards: Periodic Inspection, USAF Series F-15A/B/C/D Aircraft*, Change 20, 15 August 1999, i to 3-11.
36. Scott Finley, Chief Analyst, Headquarters USAF/A4MY; data retrieved from Air Force Portal, Applications: Reliability and Maintainability Information System (REMIS - USAF), Scheduled Maintenance Downtime for F-15 and KC-135 Aircraft, FY1997-FY2006, [Online] Available: https://www.my.af.mil/merlinprod/MissionPerformance/mission_WSA_unit.asp, accessed 31 January 2007.
37. Air Force Portal, Applications: Multi-Echelon Resource and Logistics Information Network (MERLIN), Mission Performance, Weapon Systems Availability for KC-135, FY97-FY06, [Online] Available: https://www.my.af.mil/merlinprod/MissionPerformance/mission_WSA_unit.asp, accessed 31 January 2007. Larry Klapper, Financial Analyst, Air Force Cost Analysis Agency (AFCAA), data retrieved from AFTOC database, CAIG elements for F-15 and KC-135 fleets, 6 February 2007.
38. TO 1C-135A-6WC-1, *All 135 Aircraft: Preflight/Postflight/Hourly Post-Flight Inspection Workcards*, Change 10, 1 August 2005, I-14.
39. TO 1C-135A-6WC-2, *All -135 Aircraft: Periodic Inspection Workcards*, Change 5, 1 August 2005, I-01.
40. Scott Finley, REMIS - USAF, Scheduled Maintenance Downtime for F-15 and KC-135 Aircraft.
41. "Major Commands," *Air Force Magazine, Journal of the Air Force Association: 2006 USAF Almanac* 89, No 5, [Online] Available: http://www.afa.org/magazine/may2006/0506majcoms.pdf, May 2006, 114-116.
42. Scott Finley, REMIS - USAF, Scheduled Maintenance Downtime for F-15 and KC-135 Aircraft, and Air Force Portal, Applications: MERLIN, Mission Performance, Weapons Systems Availability for KC-135, FY97-FY06, 31, accessed January 2007.
43. Larry Klapper, AFTOC database, CAIG elements for F-15 and KC-135 fleets, 6 February 2007.
44. The extra days were derived from the total time an inspection currently requires—the HPO-1 takes 6 days to complete with 30 technicians working 8 hours for 1,440 total man-hours; the HPO-2, 8 days at 1,920 total man-hours; and the PE, 10 days at 2,400 total man-hours. This was compared to the number of days required with 6 less technicians per inspection.
45. DOD, *PBD 716: Directed Offsets - Air Force*, 2.
46. Colonel Schumacher, "Enterprise View of Aircraft Inspections," briefing, slides 36-37.
47. Brig Gen S. Gilbert, Director of Air Force Smart Ops, Headquarters USAF/A3-SO, "AFSO21: Air Force Smart Ops for the 21st Century," 3 January 2007, slide 5.

48. Colonel Schumacher, "Enterprise View of Aircraft Inspections," briefing, slide 34.
49. Scott Finley, REMIS - USAF, Scheduled Maintenance Downtime for F-15 and KC-135 Aircraft. The 12 days of scheduled maintenance downtime includes 2 days required to deliver the aircraft to and from the regional site.
50. *Ibid.*
The 14 days of scheduled maintenance downtime includes 2 days required to deliver the aircraft to and from the regional site.
51. Colonel Schumacher, "Enterprise View of Aircraft Inspections," briefing, slide 36.
52. *Ibid.*
53. *Ibid.*
54. Author's personal experience while assigned as the squadron maintenance officer, 60th Fighter Squadron (FS), 33rd Fighter Wing (ACC), Eglin AFB, FL. The 60 FS made Air Force history in 2000 by flying 130 sorties in a single day and 362 over 3 days; eclipsing the world record by 18 sorties for 1-day and 37 sorties for 3-day flying windows.
55. Scott Vandersall, "MSG-3," briefing, slide 4.
56. Author's discussion with Gregg Brown, Manager, Regulatory Compliance, Southwest Airlines), 23 February 2006.
57. Scott Vandersall, "MSG-3," briefing, slide 12.
58. Scott Vandersall, "MSG-3," briefing, slide 57.
59. Scott Finley, REMIS - USAF, Scheduled Maintenance Downtime for F-15 and KC-135 Aircraft.
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.
61. Air Force Portal, Applications: MERLIN, Mission Performance, Weapon Systems Availability for F-15A-D, FY97-FY06, 29 January 2007, and MERLIN, Readiness Review, 12 December 06, slide 3, [Online] Available: https://www.my.af.mil/merlinprod/MissionPerformance/mission_WSA_unit.asp, both accessed 29 January 2007.
62. Scott Finley, REMIS - USAF, Scheduled Maintenance Downtime for F-15 and KC-135 Aircraft.
63. TO 1C-135A-6WC-1, *All 135 Aircraft: Preflight/Postflight/Hourly Post-Flight Inspection Workcards*, I-14.
64. Air Force Portal, Applications: MERLIN, Mission Performance, Weapon Systems Availability for F-15A-D, FY97-FY06, 29 January 2007, and MERLIN, Readiness Review, 12 December 06, slide 3.
65. Dave Nakata, "Why Transition to a MSG-3 Based Maintenance Schedule?," 3.
66. Author's interview with Scott Vandersall, 22 February 2006.
67. Scott Vandersall, MSG-3, slide 21.
68. Scott Vandersall, MSG-3, 22.
69. Scott Vandersall, MSG-3, 57.
70. *Ibid.*
71. Larry Klapper, AFTOC database, CAIG elements for F-15 and KC-135 fleets, 6 February 2007.
72. *Ibid.*
73. Col Gene Kamena, "US Army Service Employment," briefing Air War College, Maxwell AFB, Alabama, 21 November 2006, slide 29.
74. Lt Gen Wood, Blue Horizons, slide 21.

Colonel Donald A. Van Patten *is a career aircraft maintenance officer. At the time of writing of this article he was a student at the Air War College, Maxwell AFB, Alabama. His maintenance assignments have taken him to bases in Air Education and Training Command, Air Combat Command, and United States Air Forces in Europe, sustaining F-16A/B/C/D, F-15C/D, EF/F-111E and A-10 aircraft, and other joint and NATO aircraft while assigned to Operations PROVIDE COMFORT and NORTHERN WATCH. He commanded the 33d Logistics Support Squadron and 33d Maintenance Squadron at Eglin AFB, FL, followed by a tour in the Pentagon as Chief of Base Maintenance Policy and Chief of Tanker Aircraft Sustainment in the Chief of Staff Deputate for Installations and Logistics, Headquarters, United States Air Force. Colonel Van Patten holds a bachelor of arts degree from Iowa State University, a master of science degree from Golden Gate University, a master of arts degree from the Air Command and Staff College, Air University, and a master of arts degree from Air War College, Air University. He is currently the Deputy Commander, 57th Maintenance Group, Nellis AFB, Nevada*

For Want of a Spanner

A curious minor logistical mystery of Royal Air Force History in World War II was the shortage of hand tools. This lasted well into 1943, four years after the war began and nine years after rearmament started in 1934.

Before wartime expansion, fitters and riggers did their initial course at No. 1 Technical Training School at Habton. They specialized either as engine fitters or as airframe riggers. Upon completion of the course, they were sent to squadrons where in seven years their education was completed.

At the squadron they reported to A, B, or C Flight where they were issued a toolkit. If they were transferred from one flight to another, they had to turn in their toolbox and have the contents accounted for before proceeding across the street to draw another set from their new flight. In biplane days, a fitter or a rigger assigned to a two seater not only acted as the gunner, but in colonial theaters lashed his toolbox to the wing next to the fuselage in case of a forced landing.

What makes the case of the missing hand tools so intriguing is that the historical documentation concerning the ordering of such necessary items has disappeared (meaning it has either been destroyed or it has been filed with the papers of a successor organization of unlikely title).

The first clue to the problem came from the Operational Record Book (ORB) of a repair and salvage unit (RSU) in the Middle East in 1940 which opened by noting that of the RSU's 62 personnel, only 25 had tools. So they were happy to pass on salvaged aircraft to whoever claimed them.

What this meant was that in a theater then desperate for serviceable aircraft, many were standing idle because the necessary repairs could not be made *for want of a spanner*, let alone the necessary spares.

But the matter is important because in 1943 in Burma (South-East Asia Command or SEAC), the Beaufighters of No. 26 Squadron only sortied once every 18 days due to lack of tools and spares.

The fact that the RAF had insisted on standardized nuts, bolts and other fittings meant that special tools were not needed. Unserviceability was due to the unavailability of regular tools.

Robin Higham, PhD

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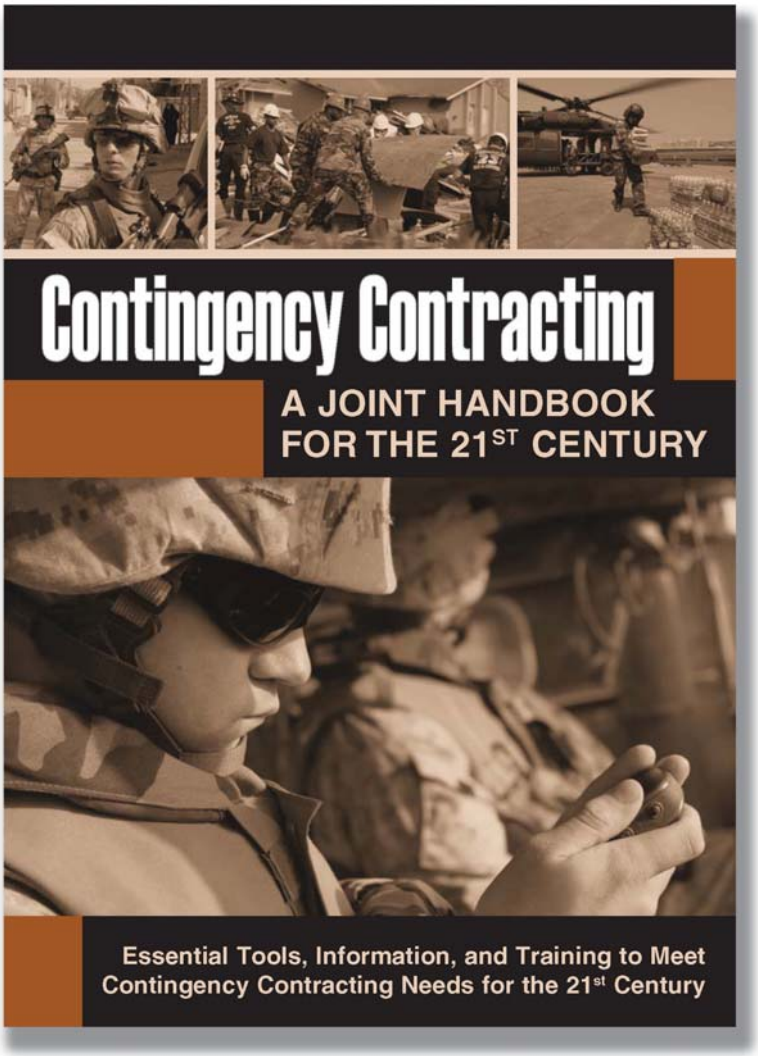

Contingency contracting support has evolved from purchases under the simplified acquisition threshold to major defense procurement and interagency support of commodities, services, and construction for military operations and other emergency relief. Today, this support includes unprecedented reliance on support contractors in both traditional and new roles. Keeping up with these dramatic changes, while fighting the Global War on Terror, is an ongoing challenge.

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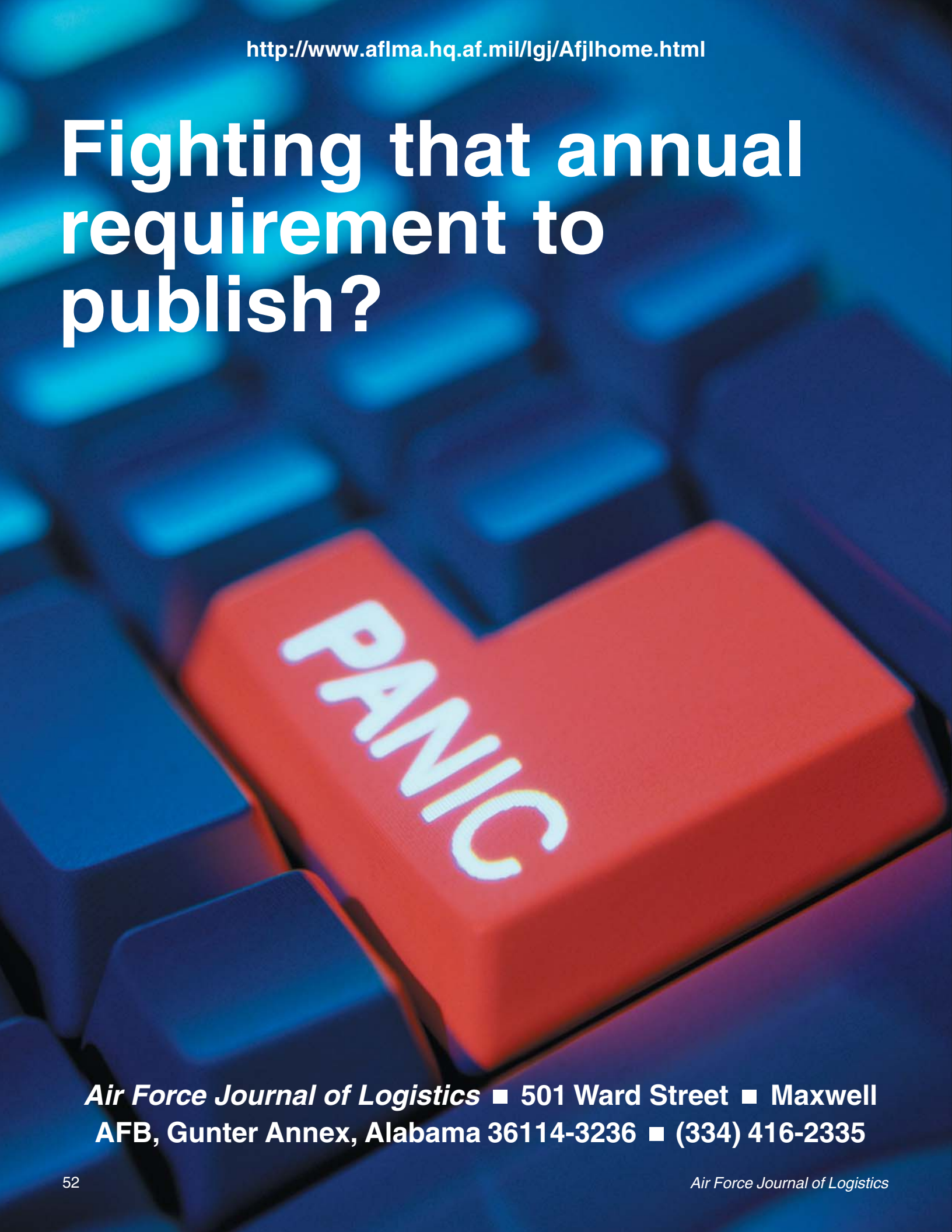

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contemporary issues

Enterprise Architecture: Origins, Tools, and Insights
Transforming Army Supply Chains: an Analytical Architecture for Management Innovation
Leaning the DoD Supply Chain: the DoD Activity Address Code

Contemporary Issues in this edition presents three articles: "Enterprise Architecture: Origins, Tools, and Insights," "Transforming Army Supply Chains: an Analytical Architecture for Management Innovation" and "Leaning the DoD Supply Chain: the DoD Activity Address Code."

In "Enterprise Architecture: Origins, Tools, and Insights" Captain Alice Marie Long, USAF, discusses enterprise architecture (EA), how it works, and most importantly, why it is needed. She also presents guidelines for implementation of EA, along with a synopsis of possible pitfalls in EA development.

Colonel Greg H. Parlier, PhD, USA, Retired, in "Transforming Army Supply Chains: an Analytical Architecture for Management Innovation" describes a practical approach for understanding the Army's extremely complex logistics system by introducing a systems framework which is guiding an ongoing project addressing major challenges confronting logistics transformation. The project focus is on inventory management policy prescriptions illuminated through the prism of an enterprise-wide supply chain analysis.

In the concluding article, Jay Barber, Global Logistics Support Center, USAF; Michael Werneke, Global Logistics Support Center, USAF; and Kevin P. Duffy, PhD, Wright State University, examine the efforts to introduce Lean to the Department of Defense (DoD) supply chain. A survey conducted by Manrodt, Vitasek and Thompson discovered that although Lean principles and concepts are being applied to the supply chain across numerous organizations, these principles are slow to be adopted in nonmanufacturing organizational settings. Importantly, the DoD is seen as an enormous organization, and an organization which is steeped in the traditional: the DoD encompasses ways of doing things which apply to supplier selection, organizational processes, and rigid hierarchical chains of command. Thus, the implementation of Lean principles into the DoD supply chain provides an extraordinary opportunity to examine a Lean implementation from two different perspectives. The first is that of applying Lean to a nonmanufacturing organization. The second perspective is to view attempts to implement Lean in a rigid organizational setting.

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Enterprise Architecture: Origins, Tools, and Insights

Alice Marie Long, Captain, USAF

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 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]

Article Acronyms

ACE – Automated Commercial Environment
ADM – Architecture Development Method
AF EAF – Air Force Enterprise Architecture Framework
AFEA – Air Force Enterprise Architecture
AFI – Air Force Instruction
AFLMA – Air Force Logistics Management Agency
AV – All Views
BRM – Business Reference Model
C4ISR – Command, Control, Communications, Computers, Intelligence, Surveillance, and Reconnaissance
CBP – Customs and Border Protection
CCA – Clinger-Cohen Act
CEA – Chief Enterprise Architect
CJCSI – Chairman Joint Chiefs of Staff Instruction
DoD – Department of Defense
DoDAF – Department of Defense Architecture Framework
DRM – Data Reference Model
EA – Enterprise Architecture
EAF – Expeditionary Aerospace Forces
eLog-21 – Expeditionary Logistics for the 21st Century
FDA – Food and Drug Administration
FEA – Federal Enterprise Architecture
GAO – General Accountability Office
HHS – Health and Human Services (Department of)
IT – Information Technology
JCIDS – Joint Capabilities Integration and Development System
LogEA – Logistics Enterprise Architecture
MAJCOM – Major Command
OV – Operational View
PRM – Performance Reference Model
SRM – Service Component Reference Model
SV – Systems/Services View
TAFIM – Technical Architecture Framework for Information Management
TAG – Technology and Architecture Group
TEAF – Treasury Enterprise Architecture Framework
TOGAF – The Open Group Architecture Framework
TRM – Technical Reference Model
TV – Technical View

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 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 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

	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

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-

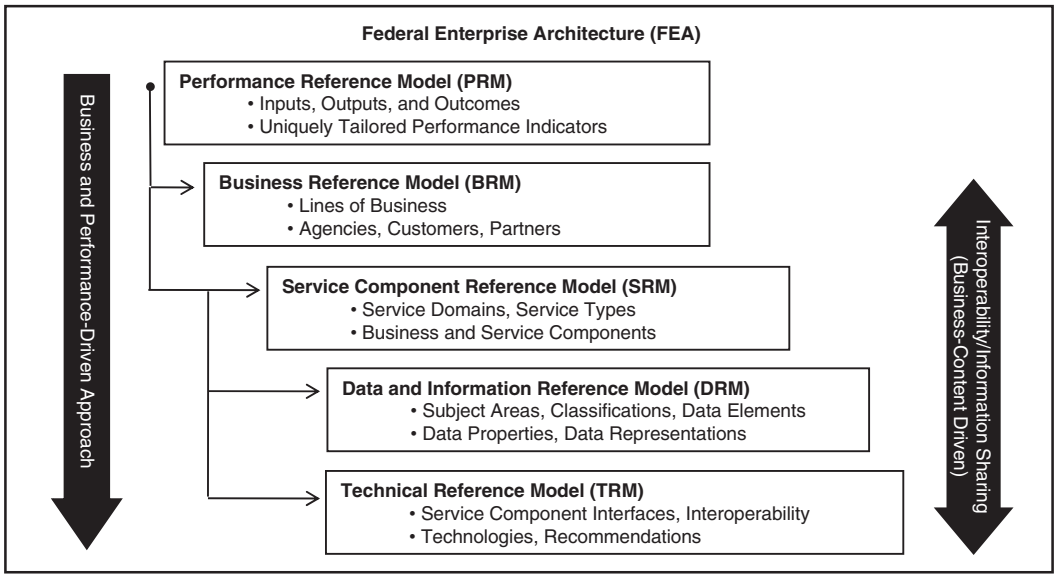

Figure 2. FEA Reference Models

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 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 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 Material 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

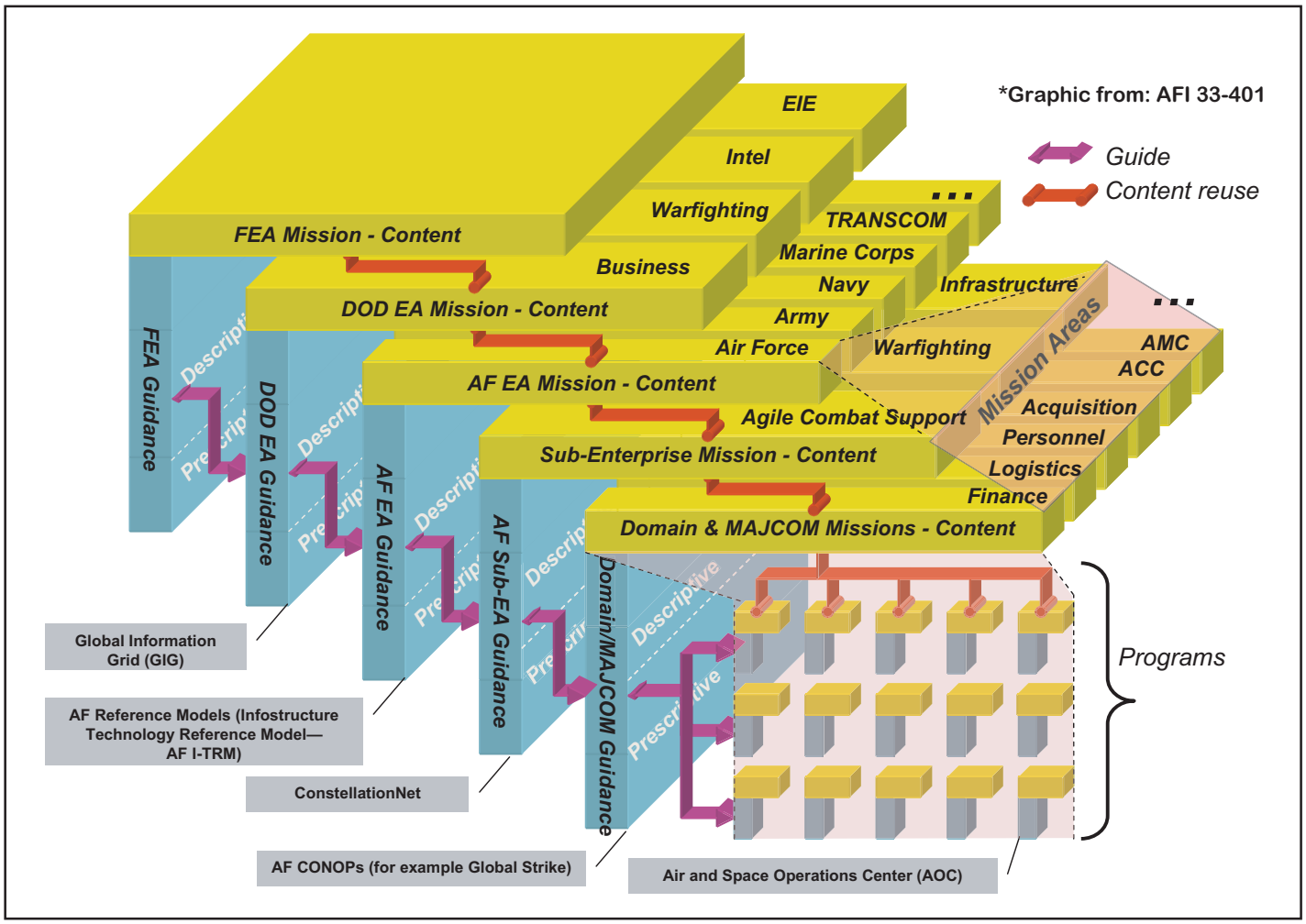

Figure 3. Federal Architecture Federation

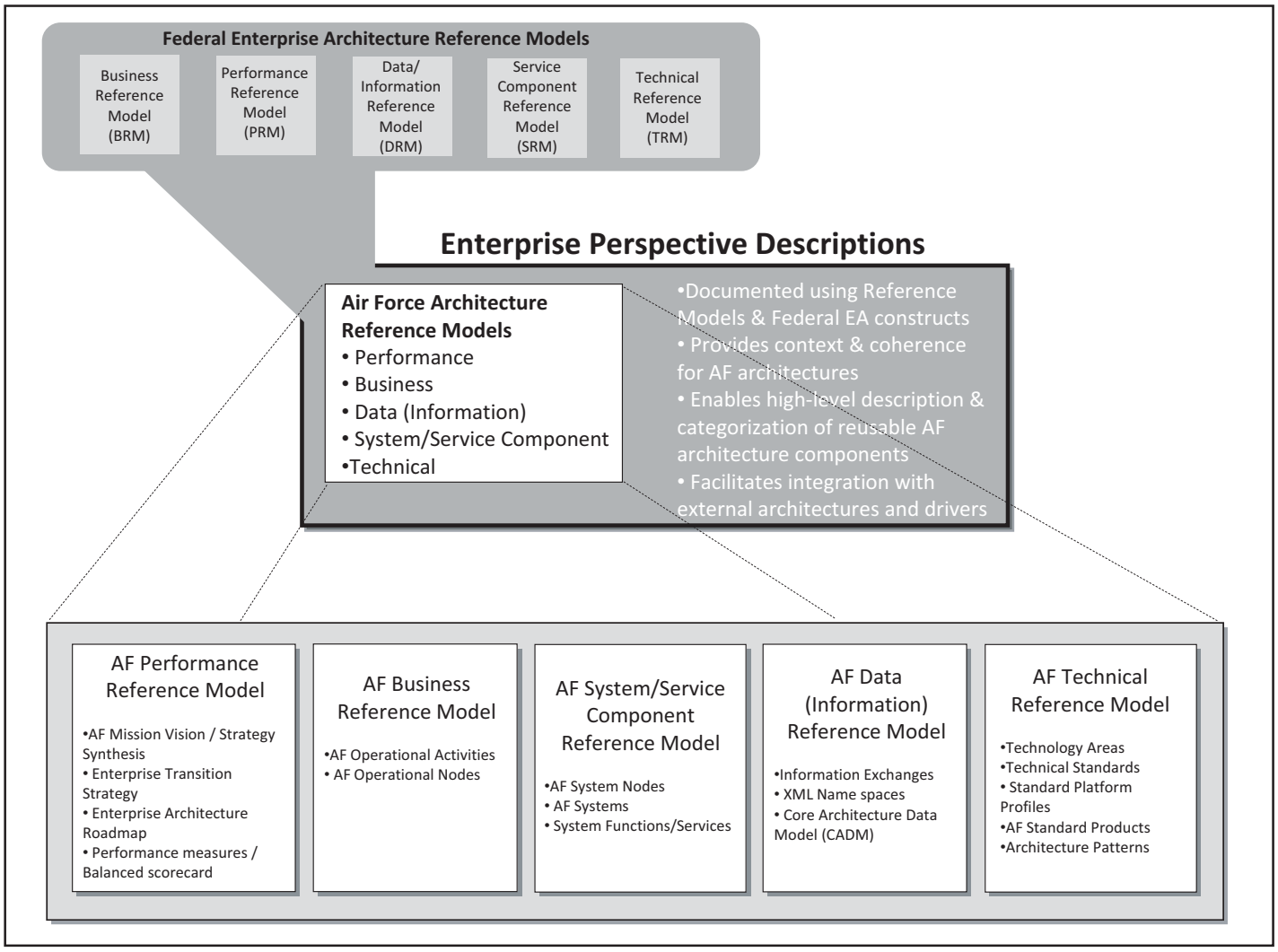

Figure 4. Air Force Enterprise Architecture Framework

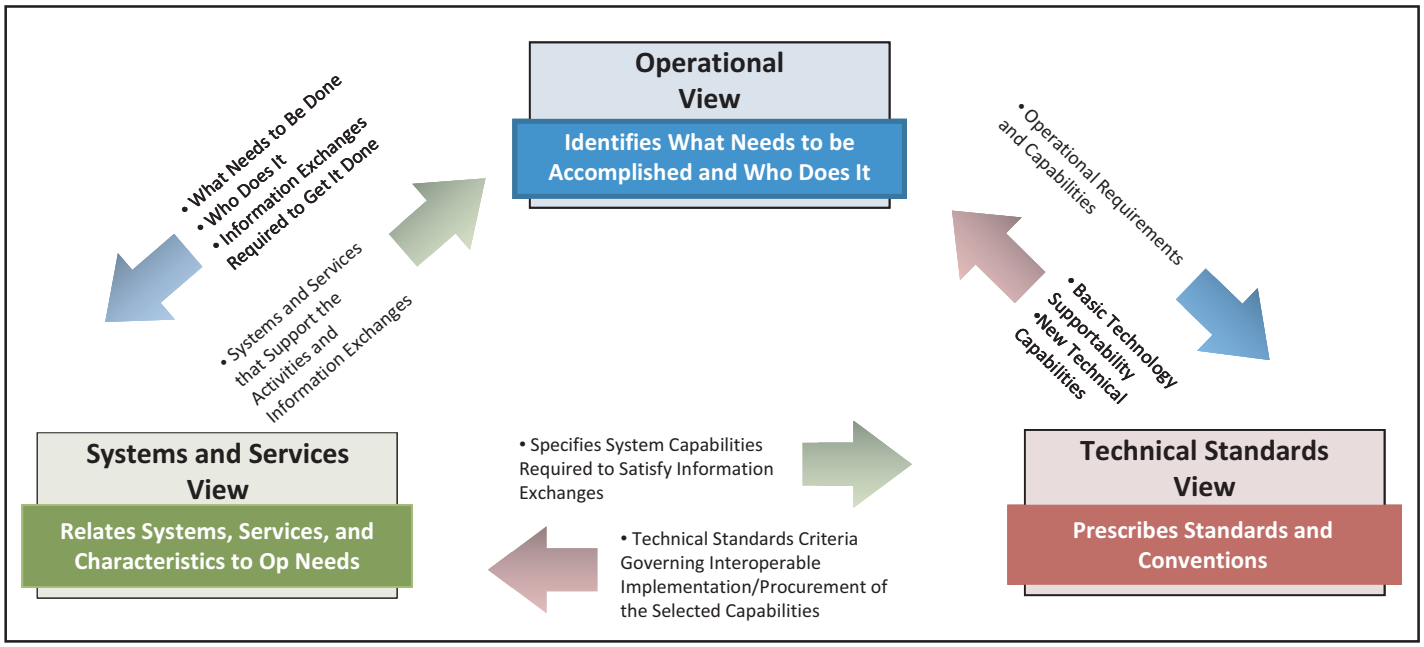

Figure 5. DoDAF Views and Linkages

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.

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.

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.

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.

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 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.

Notes

1. EEE-SA, *IEEE Standard Glossary of Software Engineering Terminology*, New York, NY: IEEE, 2004.
2. Federal Chief Information Officer Council, "A Practical Guide to Federal Enterprise Architecture," [Online] Available: www.enterprise-architecture.info/Images/Documents/Federal%20Enterprise%20Architecture%20Guide%20v1a.pdf, 2001.
3. Federal Chief Information Officers Council, "Architecture Principles for the US Government," [Online] Available: *www.cio.gov/documents/Architecture_Principles_US_Govt_8-2007.pdf , 2007.*
4. US President, Presidential Documents, "Federal Information Technology – Clinger-Cohen Act," Federal Register, 61, no. 140, 19 July 1996, 37657-376621.
5. Office of Management and Budget, Circular A-130, *Management of Federal Resources*, Washington, DC: Office of Management and Budget, 1996.
6. US Congress, "FY 05 National Defense Authorization Act," [Online] Available: http://www.ndia.org/Content/NavigationMenu/Advocacy/Action_Items/FY05_NDAA.htm, 13 October 2004, accessed 3 September 2008.
7. Chairman of the Joint Chiefs of Staff Instruction (CJCSI) 3170.01F, *Joint Capabilities Integration and Development System*, 1 May 2007.
8. Air Force Policy Directive (AFPD) 33-4, *Air Force Enterprise Architecting*, 27 June 2006.
9. R. Sessions, MSDN Architecture Center Library, [Online] Available: http://msdn.microsoft.com/en-us/library/bb466232.aspx, accessed 4 September 2008.
10. "The Open Group Introduction to the ADM," [Online] Available: http://www.opengroup.org/architecture/togaf8-doc/arch/, accessed 9 September 2008.
11. US President, "FEA Consolidated Reference Model Document," Version 2.3., [Online] Available: www.whitehouse.gov/omb/asset.aspx?AssetId=470*, October 2007*
12. Executive Office of the President of the United States, "Federal Enterprise Architecture Program EA Assessment Framework 2.1.," [Online] Available: http://www.whitehouse.gov/omb/e-gov/fea/, 2006.
13. Department of Defense, DoD Architecture Framework Version 1.5., [Online] Available: *jitc.fhu.disa.mil/jitc_dri/pdfs/dodaf_v1v2.pdf, 23 April* 2007.
14. US Food and Drug Administration, US Food and Drug Administration Homepage, [Online] Available: http://www.fda.gov/, accessed 28 October 2008.
15. Federal Enterprise Architecture Program Management Office, "Enterprise Architecture in Action," [Online] Available: www.egov.gov, accessed 29 October 2008.
16. US Department of Homeland Security, US Customs and Border Protection Homepage, [Online] Available: www.cbp.gov, accessed 31 October 2008.
17. Deputy Chief of Staff for Installations and Logistics Directorate of Transformation, "US Air Force Logistics Enterprise Architecture Concept of Operations," Washington DC: AF/A4I, 2007.

Captain Alice Marie Long *is the Systems Engineer for the Air Force Logistics Management Agency, Maxwell AFB, Gunter Annex, Alabama. She is a graduate of the Air Force Institute of Technology and holds a master of science degree in systems engineering.*

Because of my wartime experience, I am insistent on the point that logistics know-how must be maintained, that logistics is second to nothing in importance in warfare, that logistics training must be widespread and thorough.…

—Vice Adm Robert B. Carney, USN

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Transforming Army Supply Chains: an Analytical Architecture for Management Innovation

Greg H. Parlier, PhD, Colonel, USA, Retired

An army fights with its weapons but lives off its logistics…

—Military maxim

So now let us embark on our enquiry into what is true … we sometimes notice that our senses deceive us, and it is wise never to put too much trust in what has let us down…

—Rene Descartes

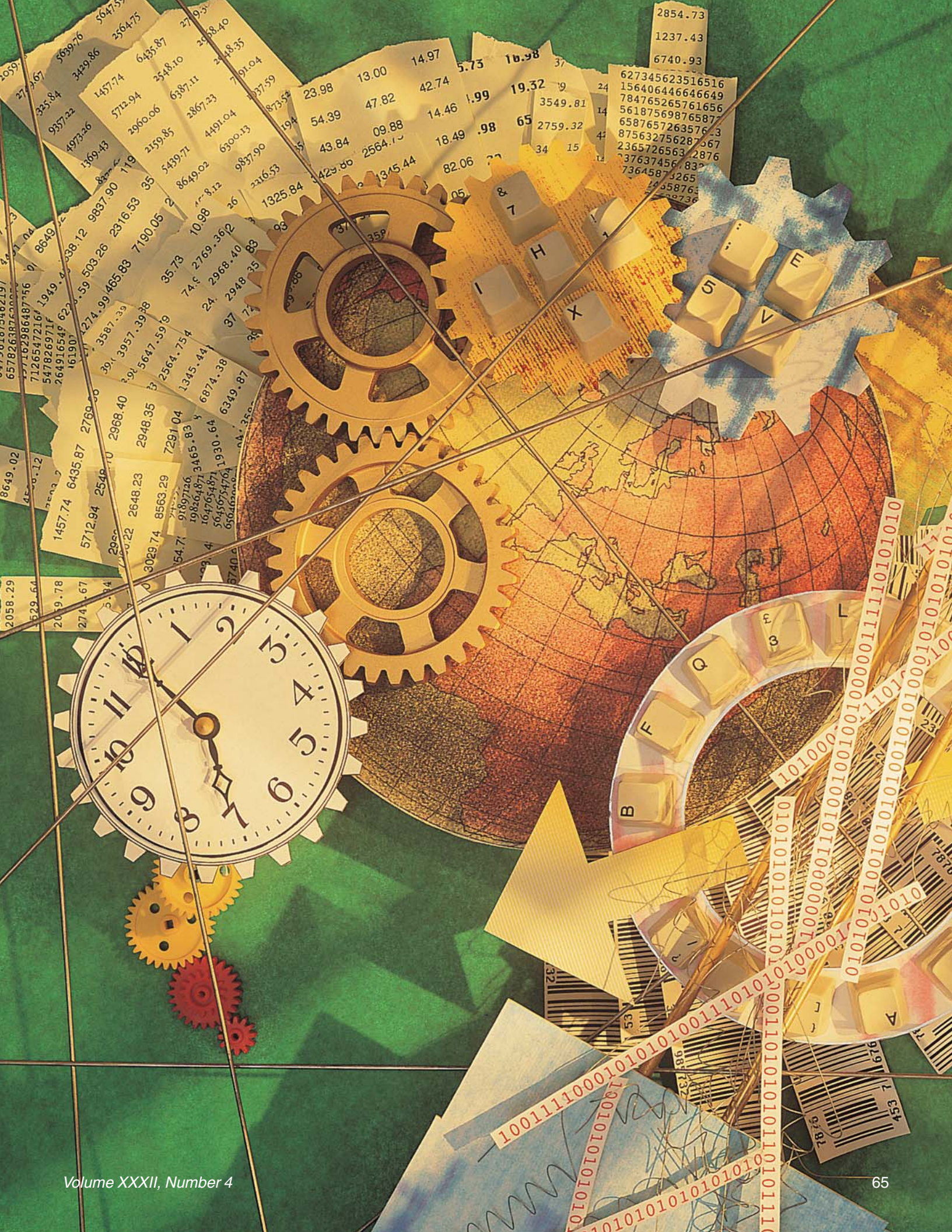
Nothing is more powerful than an idea whose time has come.

—Victor Hugo

Introduction

The US Army's logistics enterprise is truly enormous in scale and scope. However, it is not merely the size and complexity of the supply chain that causes difficulty, but rather the structure and policies within the system that are the root cause of persistent problems. Army logistics has especially suffered from several disorders which are both systemic and chronic. This ongoing research project has illuminated these problems using inventory management theory, supply chain principles, and logistics systems analysis as key sources of diagnostic power. To summarize generally, 5 years ago when the project described in this article was launched, these causal disorders and their respective effects were found to include the following:

- Lack of an empirically measured readiness production function which induces both uncertainty and variability at the point of consumption in the supply chain resulting in inappropriate planning, improper budgeting, and inadequate management to achieve readiness objectives
- Limited understanding of mission-based, operational demands and associated spares consumption patterns which contribute to poor operational and tactical support planning and cost-*in*effective retail stock policy
- Failure to optimize retail stock policy to achieve cost-efficient readiness (customer) objectives, which results in inefficient procurement and reduced readiness
- Failure to proactively synchronize and manage reverse logistics which contributes significantly to increased requirement objectives (RO), excess inventory, and increased delay times (order fulfillment) with reduced readiness
- Inadequately organized depot repair operations that may be creating a growing gap in essential repair capacity while simultaneously precluding the enormous potential benefits of a synchronized, closed-loop supply chain for reparable components
- Limited visibility into and management control over disjointed and disconnected manufacturing (original equipment



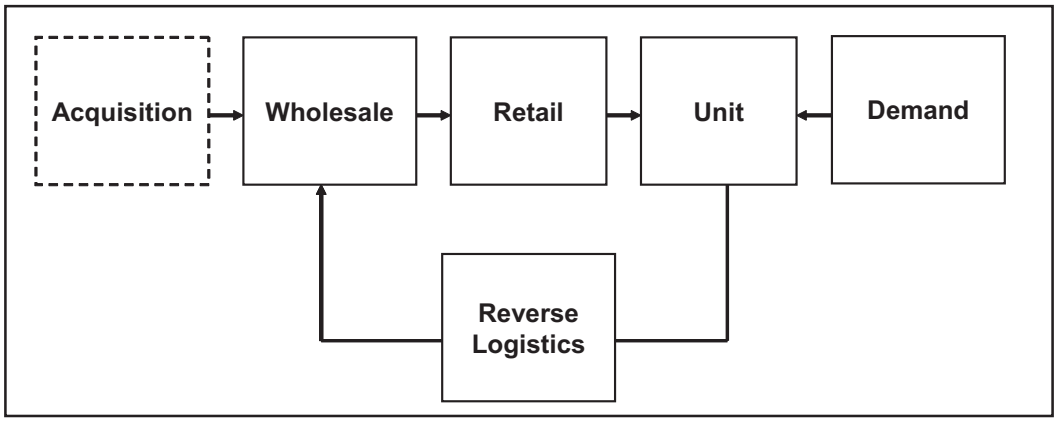


Figure 1. Multi-Stage Logistics Model

manufacturer) and key supplier procurement programs which are vulnerable to boom and bust cycles with extremely long lead times, high price volatility for aerospace steels and alloys, and increasing business risk to crucial, unique vendors in the industrial base resulting in diminishing manufacturing sources of materiel supplies, and growing obsolescence challenges for aging aircraft and vehicle fleets

- Independently operating, uncoordinated and unsynchronized stages within the supply chain creating pernicious *bullwhip* effects including high RO, inadequate stock levels, long lead times, and declining readiness
- Fragmented data processes and inappropriate supply chain measures focusing on interface metrics which mask the effects of efficient and effective alternatives, and further preclude an ability to determine *readiness return on net assets* or to relate resource investment levels to readiness outcomes
- Lack of central supply chain management and supporting analytical capacity results in multiagency, consensus-driven, bureaucratic responses hindered by lack of an Army supply chain management science and an enabling *analytical architecture* to guide logistics transformation
- Lack of an *engine for innovation* to accelerate then sustain continual improvement for a learning organization

We found the existing logistics structure was indeed vulnerable to the supply chain bullwhip. While endless remedies have been adopted over the years to address visibly apparent symptoms, the fundamental underlying disease has not been adequately diagnosed or treated, much less cured. Now, better understanding these underlying causes of failure, a new approach to logistics management is required for the US Army.

The analytical challenge is to conquer unpredictability: to better understand their sources, then attack the root causes of variability and uncertainty within each stage and their collective contributions to volatility across the system of stages—the bullwhip effect. By improving demand forecasting and reducing supply-side variability and inefficiencies within each of the stages, logistics system performance is moving toward an efficient frontier in the cost-availability trade space.

The first step in suppressing the bullwhip effect is to isolate, detect, and quantify inefficiencies within each stage and their respective contributions to system-wide aggregate inventory RO. The next step is to use this knowledge to drive inventory policy. Since Army inventories are managed to these computed ROs, reducing the value of the RO is critical to eliminating unnecessary inventory. As recommended prescriptions for improved performance are implemented in each of the stages, their respective contributions to reducing RO (while sustaining or actually improving readiness performance) can be measured, compared and assessed within a rational cost-performance framework (see Figure 2).

In general, these various contributions to the aggregate, system-wide RO (induced by the bullwhip effect) can be isolated, quantified, then systematically reduced by understanding and attacking root causes. They include the following:

- Reducing demand uncertainty by adopting empirically-derived, mission-based demand forecasting
- Reducing supply-side lead times and their associated variability
- Improving order fulfillment while reducing back orders and requisition wait times by implementing readiness-based sparing (RBS) stock policies, inventory pooling, and ultimately, tactical-level demand driven supply networks

An especially compelling and urgent need—and also one with lucrative potential benefits—is the reverse pipeline. As retrograde operations become more responsive and contribute to a synchronized closed-loop supply chain, it becomes possible to reduce RO and safety stock for specific depot-level reparable components (DLRs) while simultaneously reducing back orders and *increasing readiness (Ao – operational availability).* As these efforts are systematically pursued, the logistics system

Article Acronyms

Ao – Operational Availability
ASL – Authorized Stockage List (used once in graphic)
CILS – Center for Innovation in Logistics Systems
DDSN – Defense Driven Supply Network
DLR – Depot Level Reparable
DoD – Department of Defense
DRRS – Defense Readiness Reporting System
DSLP – Dynamic Strategic Logistics Planning
DSP – Dynamic Strategic Planning
GARCH – Generalized Autoregressive Conditional Heteroskedstic
HQDA – Headquarters, Department of the Army
IT – Information Technology
OEM – Original Equipment Manufacturer
OSD – Office of the Secretary of Defense
PLL – Prescribed Load List
RBS – Readiness Based Sparing
RFID – Radio Frequency Identification
RO – Requirement Objective
SARSS – Standard Army Retail Supply System
SSA – Supply Support Activity (used once in graphic)
SSF – Single Stock Fund
TAV – Total Asset Visibility

becomes more efficient. RO (safety stock) is reduced while performance (back orders and Ao) is increased, thereby moving toward the *efficient frontier* in the cost-performance trade space (see Figure 3).

Efficiency, Resilience, and Effectiveness

Simply recognizing that these bullwhip conditions exist does not guarantee that needed changes will actually be made. Moreover, these debilitating and persistent effects can be avoided only if long term organizational behavior and management processes are addressed.

In addition to reducing demand uncertainty, and identifying the causes and reducing the effects of supply and demand variability within each of the logistics stages, the stages must also be integrated—linked together in meaningful ways—for credible cause and effect relationships to be identified among new initiatives. Department of the Army resource allocation investment levels can then be credibly related to readiness-oriented operational outcomes (see Figure 4).

Achieving Efficiency

A recurring management challenge in complex supply chains is determining where and in what quantities to hold safety stock in a network to protect against variability, and to ensure that target customer service levels are met. In an effort to improve supply chain efficiency, an appreciation for the interdependencies of the various stages is required in order to fully understand how inventory management decisions in one particular stage or location impact other stages throughout the supply chain.

For military and aerospace logistics systems, optimizing

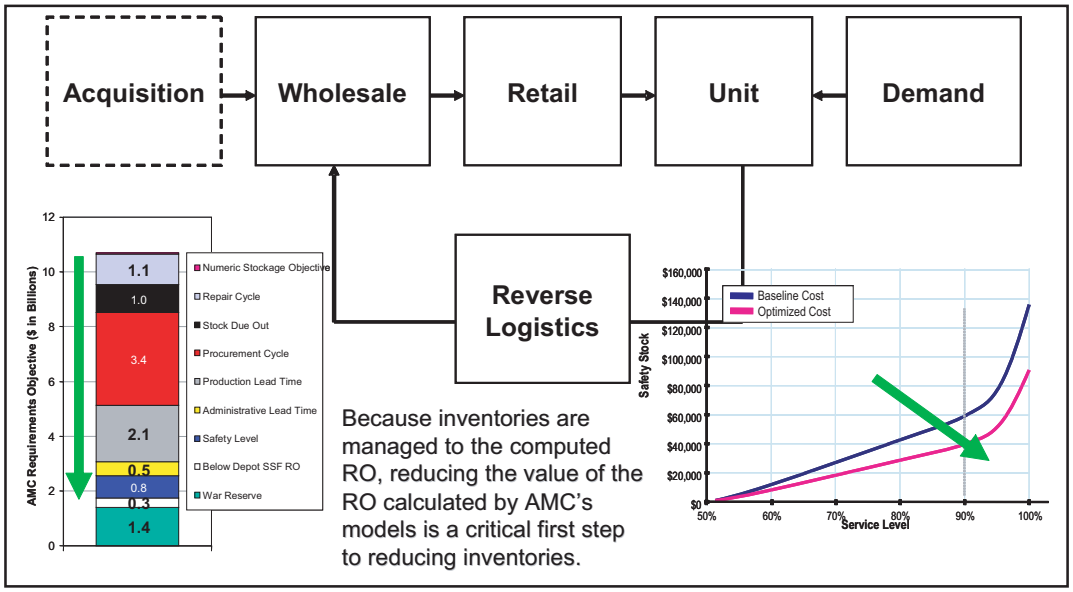


Figure 2. Improving System Efficiency—Across the System of Stages and within Each Stage

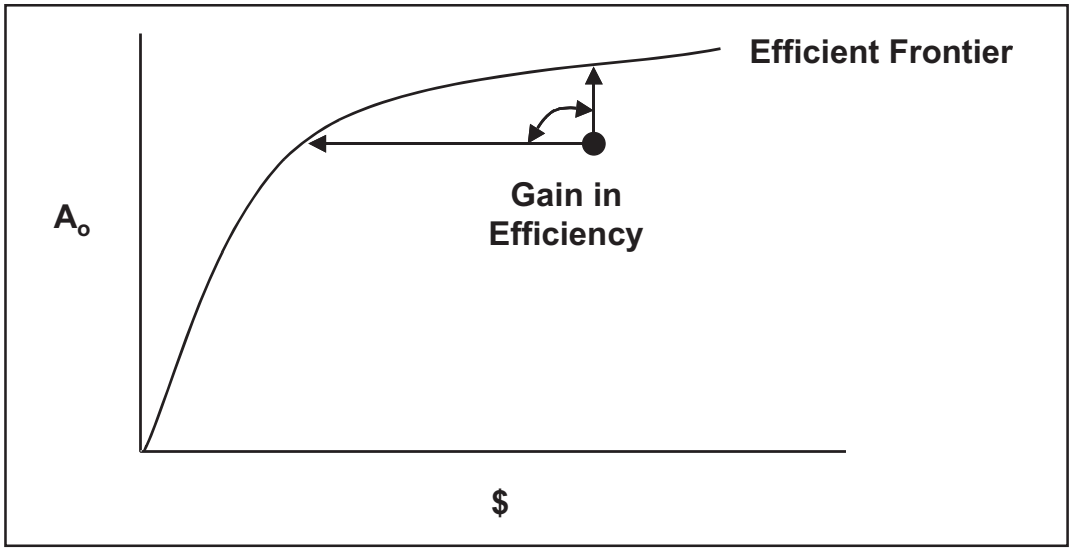


Figure 3. Achieving Efficiency in the Cost-Availability Trade Space

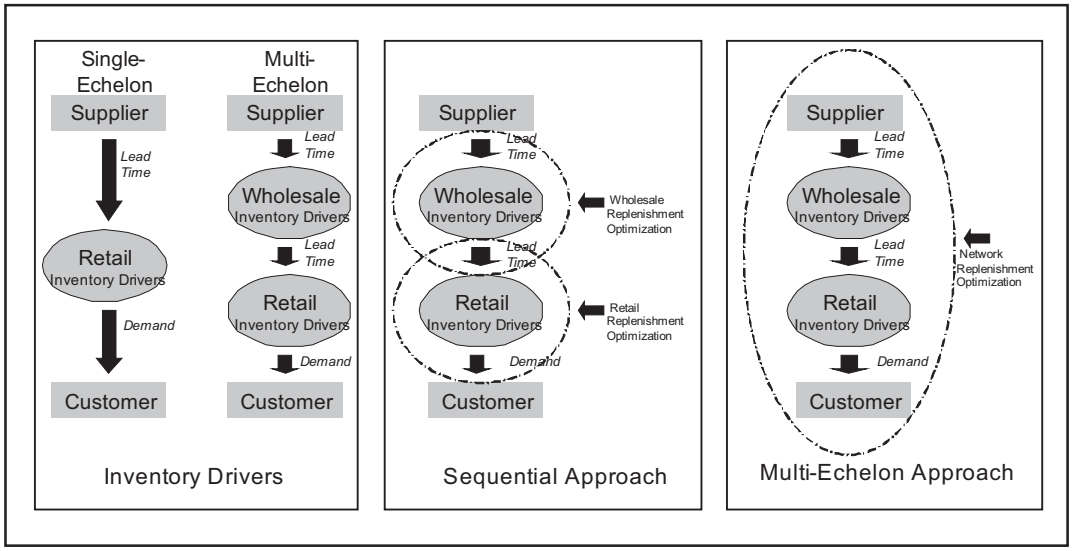


Figure 4. Multi-Echelon Integration

these decisions requires a decision support system that captures multiechelon, multi-item, multi-indenture interactions, and also the dynamics of the reverse flows for reparable components. Such a decision support system must also be linked to the various supply information transactions, depot repair and overhaul, and long term planning systems that affect the overall responsiveness, support adequacy, and capacity of the fleet supply chain enterprise—the *readiness* of the entire, globally-dispersed logistics support system.

Consequently, an integrated, multiechelon network offers several opportunities for supply chain efficiency:

- Multiple, independent forecasts in each of the stages are avoided.
- Variability in both demand and lead time (supply) can be accounted for.
- The bullwhip effect can be observed, monitored, and managed.
- Its various root causes can be identified and their effects measured, corrected, and tracked.
- Common visibility across the supply chain stages reduces uncertainty, improving demand forecasting and inventory requirements planning.
- Order cycles can be synchronized (this has special significance for DLRs in the retrograde and depot repair stages).
- Differentiated service levels (for example, Ao targets for different units) can be accommodated.
- Action can be taken to reduce unnecessary inventory and operational costs, while simultaneously improving readiness-oriented performance.

Although the computations to incorporate key variables, their relationships, and associated costs are certainly not trivial, they can nonetheless be performed using advanced analytic methods, including RBS optimization methods. Improved results are then possible and the organization will have far greater confidence that it is operating closer to the efficient frontier within the cost-performance trade space.

For military aircraft it has also been demonstrated that DLRs most directly relate to aircraft performance and, in general, minimizing the sum of DLR back orders is equivalent to maximizing aircraft availability. Significant effort has also been placed on determining optimal stock levels and locations for reparable components in a multiechelon system. While the subsequent extension of this theory has been widespread, the focus of practical implementation within the Department of Defense (DoD) has been on fixed-wing aircraft in the Navy and the Air Force, rather than rotary wing aircraft in the Army. Another structural constraint which previously precluded an integrated multiechelon approach for Army supply systems was the existence of separate stock funds used by the Army financial management system for retail and wholesale operations. In recent years, however, these separate funds have been combined into one *revolving fund*, the Single Stock Fund (SSF). In theory, this SSF should both facilitate and encourage adoption of an integrated multiechelon approach. For example, the wholesale stage now has both visibility into the retail stage and more control over stock policy in the wholesale *and* retail stages, which it previously did not have for Class IX (repair parts). It now becomes possible for Army Materiel Command to incorporate multiechelon optimization for wholesale stock levels, *in addition to retail RBS solutions*, to be directly related to readiness (Ao).

It is not possible to truly *optimize* performance output from large scale, complex systems if they have not first been *integrated*. The key integrating enabler for improved efficiency in all Army weapon system supply chains (and the more complex the system, the more crucial the enabler) is multiechelon readiness based sparing. Indeed, this is a *precondition* for Army logistics transformation.

Designing for Resilience

The intent is certainly not to blindly adopt the latest management *fad* inundating the corporate world, but rather to consider adapting proven concepts to the unique needs and challenges the Army faces. The opposite result could occur with just-in-time methods. Lean manufacturing concepts have certainly helped firms to become more competitive through the application of just-in-time principles which exchange industrial age mass for information age velocity. In addition, many of the original Lean manufacturing concepts, especially the focus on reducing *stagnant* work-in-progress inventory, have been successfully adapted for supply chain management across the entire enterprise. However, the idea of *integration*, when achieved by reducing slack or waste in the system, does not necessarily enable greater flexibility.

Furthermore, just-in-time concepts, although a powerful inventory reduction method, need stable, predictable supply chains for maximum efficiency. Even when enabled by information technology (IT), Lean supply chains can be fragile, vulnerable to disruption, and unable to meet surge requirements needed to accommodate an immediate increase in demand. In fact, recent official documents describe exactly such a condition for Army logistics in recent years. Under greater duress and the compounding stress of ongoing operations, the military logistics system has indeed resulted in a Lean supply chain without the benefit of either an improved distribution system or an enhanced information system.

A more appropriate analogy for Army logistics is a flexible, robust logistics *network*; not a serial *chain* or hierarchical arborescence (see Figure 5), but rather a network *web*—as in spider web—which is then enabled by a strong analytical foundation with supporting IT to achieve an integrated, flexible, efficient, and effective logistics capability.

The research and subsequent understanding of emergence in self-organizing systems has been rapidly advancing in recent decades, extending originally from cybernetics to incorporate growing knowledge in cognitive science, evolutionary biology, dynamic systems, stochastic processes, computational theory, and culminating now in *complex adaptive systems*. For military operations, this *network-centric* future force will be linked and synchronized in time and purpose, allowing dispersed forces to communicate and maneuver independently, while sharing a common operating picture. Conceptually, the traditional mandate for overwhelming physical *mass*, in the form of a linear array of land combat forces converging at the decisive place and time, is replaced by attaining comparable *effects* derived from dispersed and disparate forces operating throughout a nonlinear battlespace.

Our ability to logistically support these concepts, especially the notion of an agile supply network at the theater and tactical levels for Army and Joint logistics distribution, may be much closer at hand now than previously recognized. At the tactical level for example, the demand driven supply network (DDSN), which includes mission-based forecasting on the demand side and RBS, lateral supply and risk-pooling (especially for depot level reparables) on the supply side, provides the foundational basis for a more agile and resilient network *web* (see Figure 6).

Through theoretical development corroborated by recent field tests, this DDSN concept has also been shown to attain *both* improved effectiveness (Ao) and, as total asset visibility (TAV) and intransit visibility (ITV) IT-based technologies are incorporated, increasingly better efficiency. Such a tactical level DDSN is not only effective and efficient, but also both resilient and adaptive, enabling a rapid transition away from the traditional hierarchical arborescence structure, which required *mountains of iron* necessary to buffer uncertainty, inefficiencies, and rigidity toward an adaptive network design consistent with sense and respond logistics.

By applying design principles for supply chain resilience, a supply chain operating a large-scale (global), demand-driven (*pull*) system under stable and predictable demand can quickly adapt to support localized, temporary requirements that may involve considerable uncertainty, but which must be *pushed* to the customer (combat units) to achieve maximum effectiveness (mission Ao in this case). Resilient design concepts include the identification of *push-pull* boundaries separating base from surge demand using decoupling points for the placement and use of strategic capacity and inventory.

These concepts suggest, first, creating prepositioned, mission-tailored support packages designed using RBS in conjunction with mission-based forecasting. These tailored mission support packages can then accommodate replacement part needs at deployed locations where existing (host nation) sustainment is not immediately or readily available. This is an example of defining a decoupling point in the existing supply chain and creating additional slack inventory to accommodate a short-term

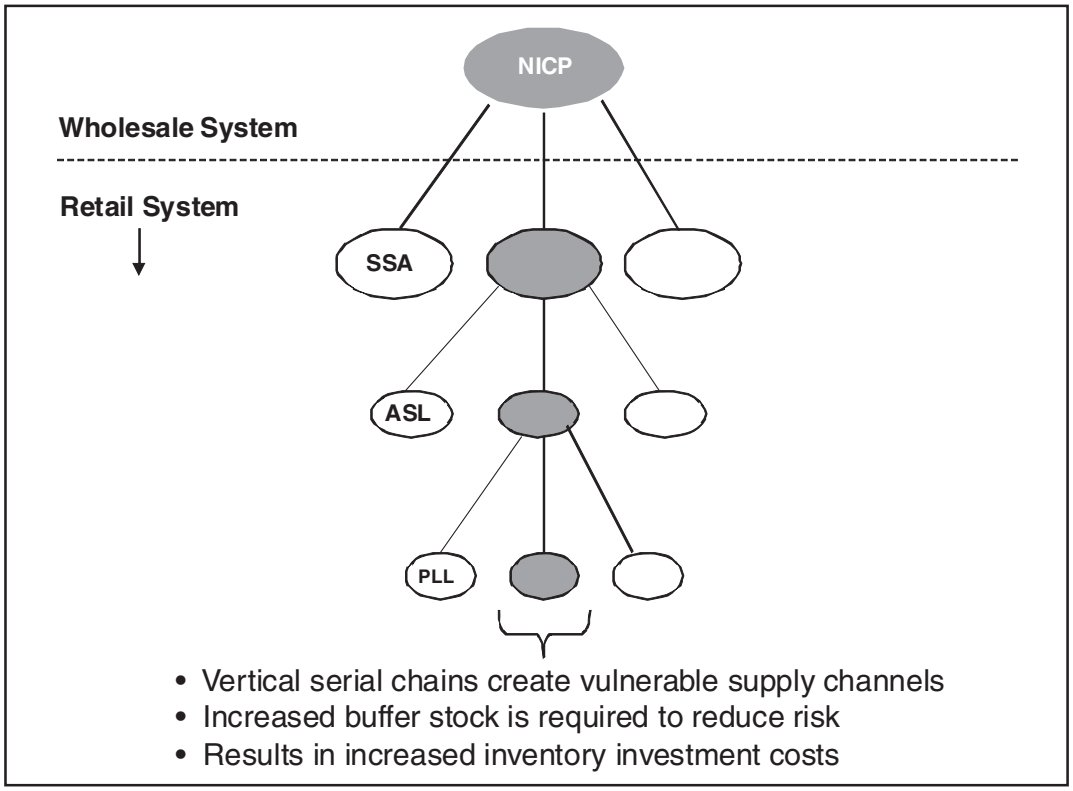


Figure 5. Current Structure: Arborescence

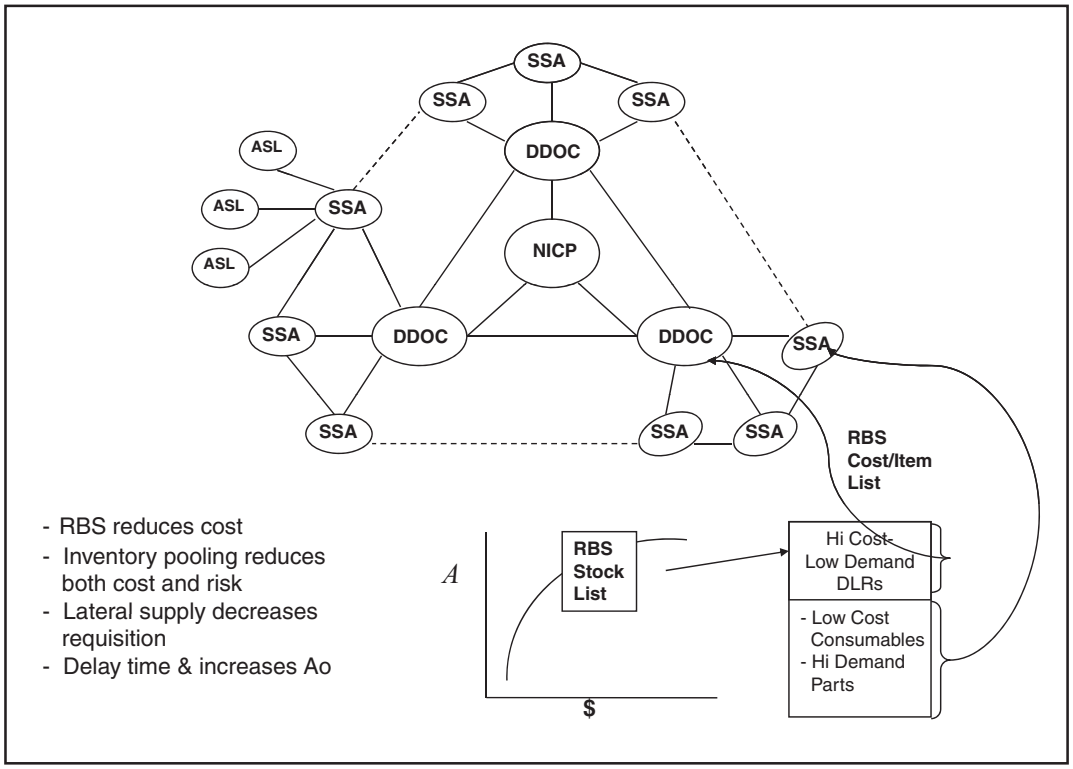


Figure 6. Demand Driven Supply Network (DDSN)

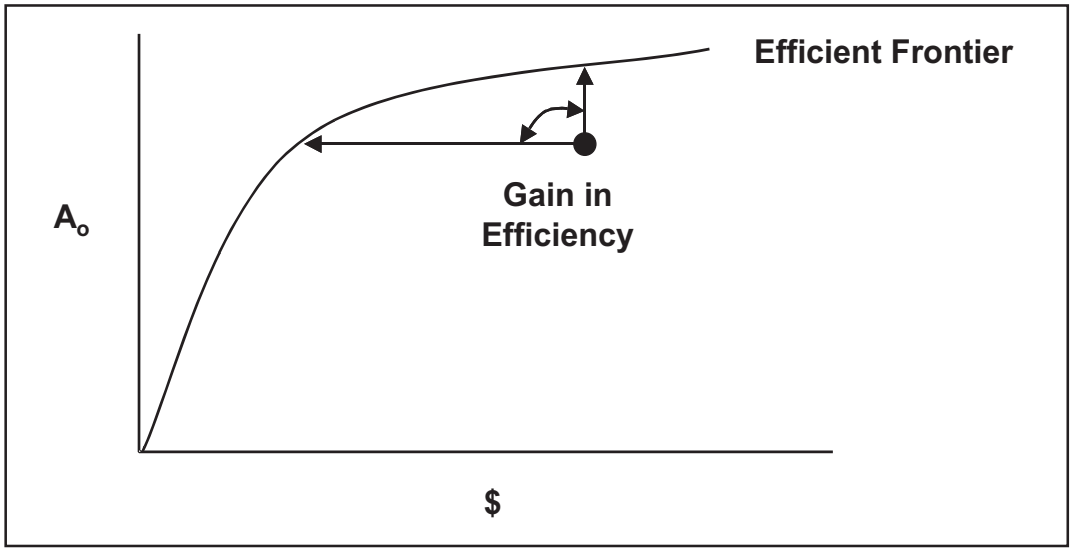


Figure 7. Achieving Efficiency in the Cost-Availability Trade Space

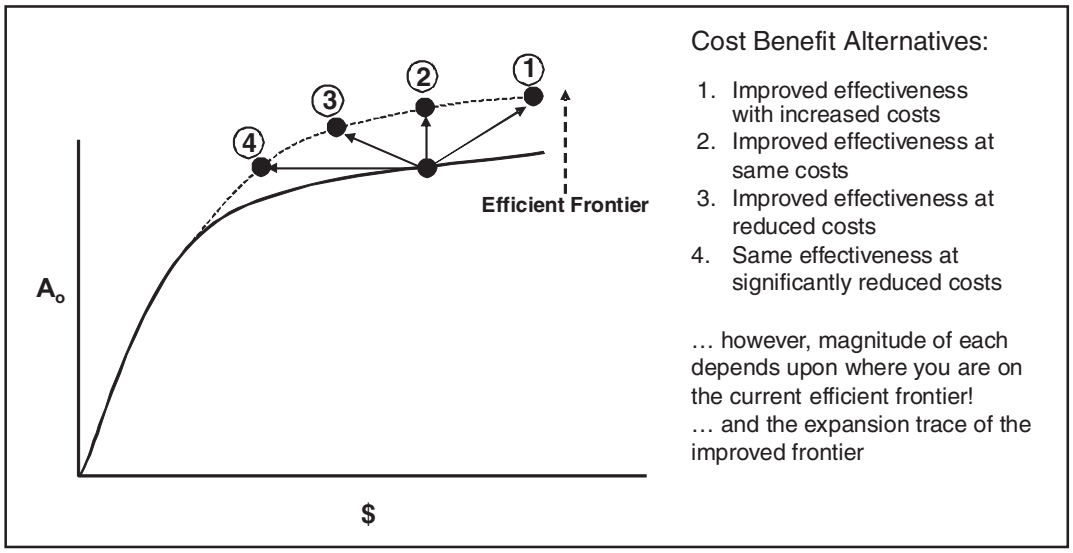


Figure 8. Increasing Effectiveness in the Cost-Availability Tradespace

surge that the existing logistics supply network infrastructure cannot immediately support.

Second, to accommodate sustained (rather than temporary) higher demand for extended operations (such as Operation Iraqi Freedom), resilient supply chain design principles suggest creating additional capacity, or relocating existing capacity, closer to the demand source. This strategic supply chain concept shifts *decoupling* points and push-pull boundaries by dynamically changing the supply chain configuration. Hence, the logistics network responds quickly to initially accommodate a short-term need with built-in slack inventory, and then adapts, if and when necessary, by actually changing its configuration to sustain increased longer-term requirements by relocating production (repair) capacity closer to the source of demand.

In summary, efforts for attaining resilience must focus on strategically designing and structuring supply chains to respond to the changing dynamics of globally positioned and engaged forces, conducting different operational missions under a wide range of environmental conditions. Ultimately, this necessitates supply chain management innovation.

Improving Effectiveness

Economists commonly make a distinction between efficiency and productivity. Efficiency refers to the output achieved from inputs using a given technology, while productivity also incorporates the results of changes in technology. By *efficient* we refer to those methods (whether policies, techniques, procedures, or technologies) which reduce uncertainty or variability both within any particular stage, as well as across the system of stages that comprise the multistage logistics enterprise. Using these methods would have the effect of moving toward the efficient frontier in the cost-availability trade space (see Figure 7). Achieving an *efficient* solution results in operating on the existing efficient frontier and implies the best possible use of existing resources *within the constraints of the current system design and business practices* using existing technology.

In contrast, a more *effective* (productive) method is one which actually shifts the existing efficient frontier, representing an improved *operating curve*. This reflects the fact that current business practices have actually changed: new or different technologies are being exploited. Cost benefit analyses can be performed on various initiatives which yield improved, but different results (see Figure 8).

Finally, the ultimate goal is to sustain continual improvement and progress over time through innovation in all of its various forms—the notion of *pushing the envelope* (see Figure 9). This is the essence of productivity gain and differentiates, in competitive markets, those commercial firms that successfully compete, survive, and flourish over extended periods from those that do not.

For a governmental activity, an engine for innovation is needed to compensate for the lack of competitive marketplace pressures, typically driven by consumer demand and customer loyalty. The most obvious engine for a military organization is imminent or evident failure on the battlefield. Failure in battle, especially if sufficient to cause the loss of a major war, clearly constitutes an *unmet military challenge* which is one of several key historical prerequisites for a revolution in military affairs.

In the absence of imminent or evident failure resulting in battlefield losses which threaten the nation's interests and values,

an alternative engine for innovation is an extensive experimentation capacity providing an ability to see the impact of alternative concepts, policies and procedures, doctrine, tactics and organizational design—a virtual or *synthetic* environment that can realistically illuminate a better way, possibly preempting future failure. This experimentation capacity must also have the institutional means to incorporate positive results into new or existing policies, doctrine, and resource programs—in short, an organizational capacity that both encourages and accommodates change.

Design and Evaluation

A viable strategy is now needed to transition from the existing state of affairs to a desired outcome defined by the characteristics presented. Inherent in developing such a strategy or plan are efforts to (1) optimize the allocation of limited resources and (2) understand and anticipate in advance the consequences, likely outcomes, and risks associated with an unlimited array of tasks that must be selected, sequenced, and synchronized for implementation.

These two analytical approaches—optimization modeling and predictive modeling—must be used together in a complementary manner to illuminate a viable plan for implementation. They provide an analytically-based strategy to link means (resources) with ways (concepts and plans) to achieve desired ends (objectives): an *analytical architecture* to guide logistics transformation.

The modeling and simulation methodology outlined in the next sections will provide this much-needed analytical capacity and could constitute a *dynamic strategic planning* capability for logistics transformation. The purpose of this engine for innovation, regardless of the form it ultimately takes, is to provide large-scale systems simulation analysis and experimentation capacity and expertise needed to serve as a credible test bed. This capability will generate the compelling analytical arguments needed to induce, organize, sequence, and synchronize the many changes needed to gain momentum, then accelerate transformation for Army logistics, including those identified and described previously. The purpose, function, and relationships of key components of this enabling analytical architecture are described in the following paragraphs.

Multistage Supply Chain Optimization

Evolutionary progress for an Army logistics transformation trajectory can be easily imagined along a spectrum transitioning from legacy-reactive to future-anticipatory concepts.

- Reactive, cumbersome, World War II-era mass-based, order and ship concept where *days of supply* is the primary metric
- Modern supply chain management incorporating velocity-based, sense and respond concept where *flow time* is the metric
- Adaptive and dynamic, inference-based, autonomic logistics network concept to anticipate and lead, where the metrics are *speed and quality of effects*.

However, a clearly defined implementation scheme for transformation is certainly not self-evident. Analytical methodologies are needed to properly sequence the vast array of new initiatives, modern technologies, process changes, and innovative management policies in cost-effective ways. Which ones are dependent upon others as *enablers* for their success? How many can be done in parallel? For those that can be, will it be possible to identify and quantify the different effects of their respective contributions? Will the synergistic consequences of interactions among complementary initiatives be measurable? Which ones may be precluded by combinations of other, more cost effective options? And how can we be assured that these

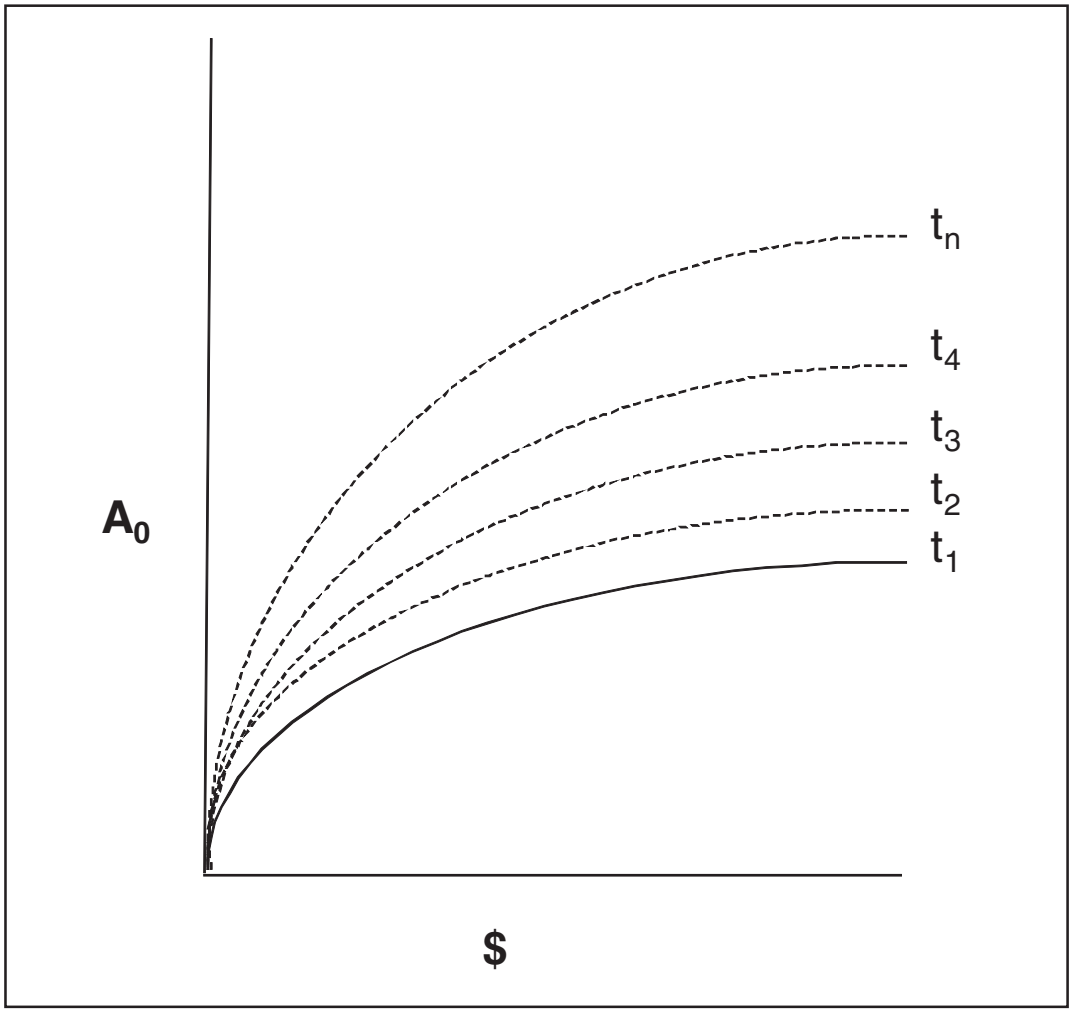


Figure 9. Pushing the Performance Envelope in the Cost-Availability Tradespace

various initiatives are not inadvertently discarded because their potentially positive effects on readiness are lost in the existing noise of such a complex, massive supply chain? In short, how can cause and effect be disentangled as transformation proceeds?

The earlier use of a multistage conceptual model to analyze the Army's logistic structure naturally lends itself to the use of dynamic programming or a comparable problem solving technique. In this multistage, graphical example, the challenge is to determine the optimal allocation of a defined budget across a range of initiatives associated with these several logistics stages. Consideration must be given to various constraints that may be imposed within each of the stages as well. The overall goal is to maximize output from the system of stages - readiness (that is Ao).

From a practical perspective, this approach also reinforces the crucial importance of developing a clearly defined, empirically measured readiness production function, and adopting RBS stock policies as enabling prerequisites to realize further cost-effective improvements to the system. For example, if the link between the unit stage (where readiness is produced for specific capabilities) and the retail stage (where management policy has not been optimized to desired readiness objectives (Ao) by adopting RBS), then the potential positive effects of a wide range of other improvements throughout the supply chain will not be clearly visible and fully realized. Additionally, potential investments should not be chosen on an individual basis, but rather on how they interact with each other. Otherwise, their real effects will simply be lost in the downstream noise of a very volatile, disconnected, and inefficient supply chain.

Dynamic Strategic Planning

Second, use of a multiperiod model must be incorporated into logistics transformation to accommodate both the extensive and extended nature of this enormous undertaking. As events occur and a transformation trajectory evolves, a mechanism is needed to routinely update the optimal solution which, inevitably, will change over time due to (1) the inability to perfectly forecast future conditions, (2) consequences of past decisions which do not always reveal the results expected, and (3) the opportunities provided by adaptation and innovation as they materialize and offer improved solutions requiring new decisions.

This dynamic strategic planning (DSP) approach is, in essence, a multiperiod decision analysis challenge which also encourages and assists in identifying, clarifying, and quantifying risk to the transformation effort. Risk assessment, a precursor to risk management, is needed to reduce and mitigate the inevitably disruptive consequences of any major transformative effort with all the uncertainties surrounding significant change.

Most planning methods generate a precise, optimized design based upon a set of very specific conditions, assumptions, and forecasts. In contrast, DSP instead presumes forecasts to be inherently inaccurate ("the forecast is always wrong") and therefore builds in flexibility as part of the design process. This engineering systems approach incorporates and extends earlier best practices including systems optimization and decision analysis. DSP allows for the optimal solution—more precisely, optimal policy—which cannot be preordained at the beginning of the undertaking, to reveal itself over time while incorporating risk management: a set of if-then-else decision options that evolve as various conditions unfold which cannot be predicted with certainty. This planning method yields more robust and resilient system designs which can accommodate a wider range of scenarios and future outcomes than those more narrowly optimized to a set of specific conditions. Though perhaps easier to engineer and manage, traditional optimal designs can quickly degenerate toward instability when such conditions no longer exist.

These observations suggest that large-scale, transformational endeavors are much more than conventional *construction* engineering efforts. They represent a major human enterprise where effective managerial decisionmaking requires a thorough understanding of the evolution and dynamics of the change undertaken. New software tools now make it possible for managers to actively participate in the development of these system dynamics models, so-called management *flight simulators*, which have become the basis for learning laboratories in many organizations.

Army logistics transformation will benefit enormously from such an application. Since supply chain behavior often exhibits persistent and costly instability, a stock management structure can be used to model and explain these effects. Since this structure involves multiple chains of materiel stocks, information and financial flows, with resulting time delays; and because decision rules often create important feedback loops among the interacting operations of the supply chain, system dynamics is well suited for modeling and policy design (see Figure 10).

Much of the management literature in business process reengineering emphasizes finding, then relaxing, major bottlenecks in the existing manufacturing or operations process. Focusing improvement effort on the current bottleneck immediately boosts throughput, while effort on nonbottleneck activities is wasted. However, relaxing one constraint simply enables another to develop as time progresses. Obviously, waiting for each successive bottleneck to occur would prolong and retard rather than accelerate continuous improvement. The value of system dynamics modeling is accelerating this understanding by exploring the implementation of different sequences in a synthetic (simulated) environment. By using the model to anticipate and accelerate this shifting sequence of bottlenecks, a prioritization scheme for these many initiatives can be developed. For the Army, a system dynamics model of the supply chain has the potential to guide and help accelerate logistics transformation by optimally sequencing and synchronizing the vast array of initiatives that have been suggested for implementation.

Decision analysis, the second major analytical component in the evolution of DSP, enables structuring the combination of system dynamics-enabled design choices so they can be made in stages as a system evolves over time. Cost-effective options can be evaluated to determine the best pattern for system development depending on how uncertainties, both within the system and external to it, are resolved over time. Thus, DSP defines an optimal strategy or policy rather than a fixed plan.

The most recent DSP improvements have focused on incorporating means to evaluate and build flexibility into designs. These include real options and robust design methods which enable calculation of the value of flexibility which was not previously considered. Consequently, flexibility as an attribute of engineering systems design was systematically neglected. Real options, applied to real physical systems, is an adaptation of options analysis which was developed for and has

been applied extensively in financial markets. Recent and ongoing applications of this newest aspect of DSP indicate the approach leads to substantial improvements in design. Also, embedding flexibility into diverse systems already optimized for performance under traditional deterministic concepts is leading to substantial savings in many cases.

Operational and Organizational Risk Evaluation

In conjunction with DSP, a wide variety of analytical methods should be used to understand, evaluate, and reduce risk during logistics transformation. Risk can take on different connotations depending upon the application. Accordingly, we address the following two concepts:

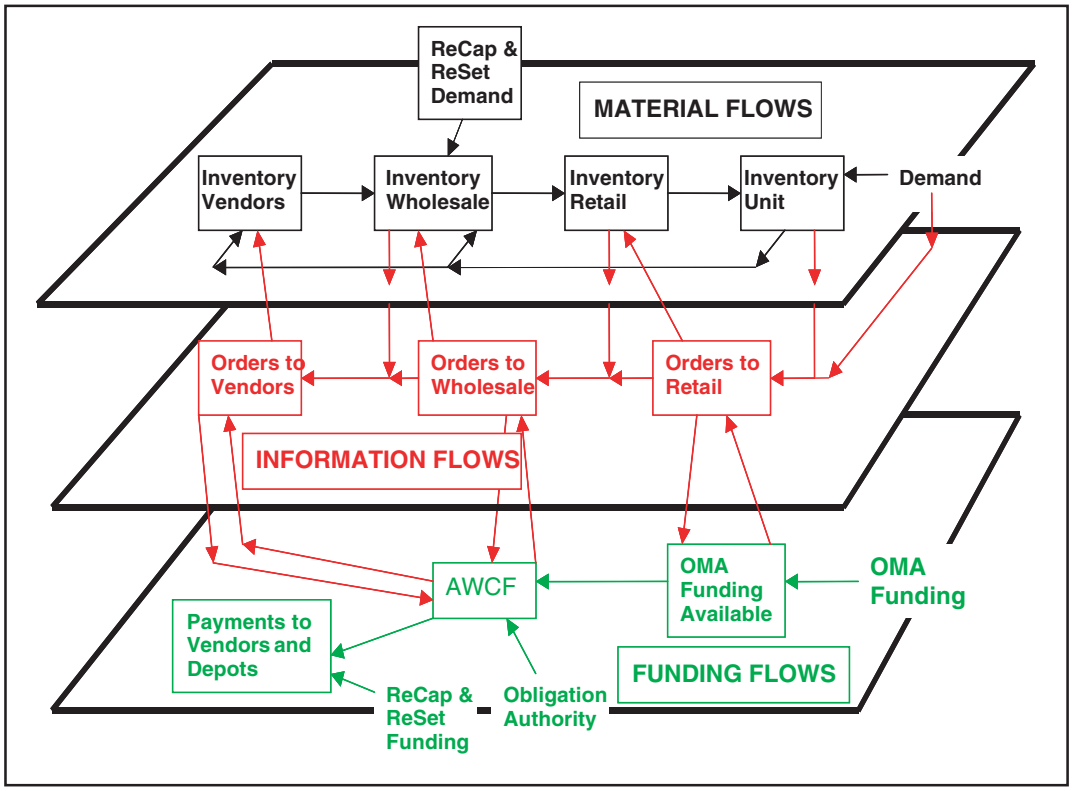


Figure 10. Supply Chain Flows

- Operational risk faced by the logistics system responding to various shocks, supply chain disruptions, and mission requirements that may not have been anticipated.
- Organizational risk to the Army logistics community, including the combination of investment, or programmatic, risk associated with new project undertakings, and the larger impacts induced by transformation uncertainties associated with organizational change at a difficult and challenging time. Operational risk, in this decision analysis context, consists of assessing both the likelihood of a particular adverse outcome and the consequences of that outcome.

Practical management frameworks have recently been developed to systematically identify supply chain vulnerabilities, assess risk, and then formulate strategies to reduce those vulnerabilities and mitigate risk. Various sources and potential causes of disruption are then bundled into associated risk categories. Analytical *tool kits* can be applied to examine specific effects and larger consequences for these risk categories, then supply chain modeling and simulation is used to analyze, evaluate, and compare alternative operational strategies and their respective costs.

Those strategies which reduce disruptive risk and enhance supply chain resilience, while simultaneously improving both efficiency and effectiveness, are ideal candidates for accelerated implementation. Two practical risk mitigation strategies which impact all three supply chain system performance objectives (efficiency, resilience, and effectiveness) are (1) a demand-driven supply network (DDSN) which reduces buffer inventory, improves readiness, and provides tactical agility, and (2) theater-level decoupling points to enhance operational agility and flexibility by providing, respectively, *slack inventory* for short, specific mission surge needs (such as humanitarian operations) and, when necessary, *slack capacity* for long-term increases in demand to sustain in-theater operations.

To address organizational (rather than operational) risk for Army logistics transformation, a variety of virtual, constructive, and live simulation methods (especially analytical demonstrations, field testing, and experimentation) can identify early on which technologies or new methods warrant further consideration. This process enables differentiating those appropriate or sufficiently mature for implementation from other methods that are not. In this context, organizational risk consists of the combined effects of both uncertainty of outcomes (simply not knowing the impacts of various alleged improvements on the logistics system) and also the uncertainty of future costs incurred as a consequence of either adopting (or failing to adopt) particular courses of action.

An example of this accelerating *crawl-walk-run* approach is the sequence of experimentation and testing adopted by this project to first demonstrate, through rigorous analytical experimentation using the UH60 aircraft in the 101st Airborne Division, the potential value of adopting RBS as aviation retail stock policy. These insightful, positive results then provided impetus for more widespread field testing with several aircraft types in an operational training environment at Fort Rucker.

Confidence and credibility in a new, different method have been gained through experience while significantly reducing the uncertainty initially surrounding the new initiative. And return-on-investment results clearly reveal reduced investment costs while still meeting or exceeding aircraft training availability goals.

Logistics System Readiness and Program Development

The final enabling analytical component includes the development, refinement, and use of econometric and transfer

function models. This capability is needed so that the Office of the Secretary of Defense and Headquarters Department of the Army level budget planners and resource programmers can relate budget and program investment levels with associated performance effects, including future capability needs and desired readiness outcomes. New impetus for this long-recognized need is now provided by DoD Directive 7730.65, which requires developing and implementing a new Defense Readiness Reporting System (DRRS). The Services, as *force providers*, generate and maintain military capabilities which are then provided to the regional combatant commanders to accomplish specified missions. Each Title 10 *function* consists of significant institutional resources, organizations, and programs which collectively define systems. Hence, a measure of each system's ability to achieve its respective goal can be defined as its *readiness* (for example, logistics system readiness).

Application of this systems approach using supply chain management concepts will help to identify constraints and weak links that are inhibiting desired readiness output (Ao), thus reducing the overall strength of the logistics chain. Marginal investment resources should then be spent on strengthening these weak links. OSD and the Services are pursuing many logistics initiatives, but as the supply chain structure is improved and refined, the logical next step is to understand and report the ability and capacity of the chain to generate output commensurate with its purpose.

New supply chain management concepts are incorporating geospatial sensors and automatic identification technologies to enable TAV and the transition toward adaptive supply chains. In particular, radio frequency identification (RFID) is expected to significantly reduce transaction error rates while also providing near real-time, high volume data. Although these new technologies hold great potential, it is unlikely that legacy software and enterprise resource planning (ERP) systems will be able to provide improved decision support and fully extract all of the potentially useful information contained in these high volume data streams.

Recent forecasting advances have yielded more accurate and precise results. These models, described as generalized autoregressive conditional heteroskedastic (GARCH), are able to significantly reduce the error term by better quantifying interaction and lag effects among the explanatory variables and time series within the model. As the volume of data increases, the ability of GARCH techniques to better disentangle and explain cause and effect relationships, while reducing forecasting error (unexplained model variance) improves. One project initiative involves examining the application of GARCH to RFID-generated supply demand data for units engaged in ongoing military operations in Iraq. Early results are promising, indicating that GARCH is yielding order of magnitude improvements for predictive performance compared to standard methods.

In the near term, however, driven by the new DRRS mandate and enabled by supply chain concepts, econometric modeling and dynamic forecasting to understand, measure, and monitor Army logistics as a readiness-producing system, a conceptual framework has emerged for a Logistics Readiness and Early Warning System. The purpose is not only to assess and monitor supply chain capacity to efficiently and effectively support current requirements, but also to anticipate its ability to responsively meet a range of future capabilities-based requirements as well. The objective is to overcome funding-induced instability manifested in periodic *boom and bust* cycles.

As Figure 11 portrays, three elements would interact in a *feedback-alert-warning* cycle. Automated monitoring continuously tracks and forecasts both tactical readiness (Ao) and supply chain parameters, then signals an alert if there is a decline in projected readiness or adverse trend in metrics. Management Assessment then validates an alert, quickly evaluates the potential problem, and assesses the impact of current and planned resource allocation as well as other technical initiatives which might mitigate or improve the logistics projection. After Headquarters Department of the Army (HQDA)-level policy analysis and review, policy response acts to prevent a shortfall while minimizing recognition and resource response lags. This responsive link to program development is absolutely crucial to an adaptive demand network. Historically, however, this response has significantly lagged or been missing altogether causing boom and bust cycles in resource programming, thus precluding viable resource-to-readiness frameworks for management decisions.

Further developed and refined over time, these forecasting models can increasingly be used for future capability forecasting, program requirements determination, and readiness prediction. These models should constitute part of a Logistics Readiness and Early Warning System contributing toward the DoD mandate for a larger DRRS by linking Army PPBES (Planning, Programming, Budgeting, and Execution System) to operational planning systems (readiness). The goal is to relate planning guidance, funding decisions, and execution performance in meaningful ways, all of which are informed by this supply chain health monitoring and management concept.

Accelerating Transformation

Several agencies and organizations with logistics modeling and supply chain simulation capabilities should now be integrated into a more formal research consortium to better coordinate their efforts and reinforce their respective strengths. This synergistic effort will facilitate properly sequenced field tests, experiments, and evaluation with supporting modeling, simulation, and analysis. Furthermore, these organizations should form the nucleus of an engine for innovation for logistics transformation—a Center for Innovation in Logistics Systems (CILS).

The CILS organizational construct consists of three components which essentially comprise the core competencies (mission essential tasks) for the center (see Figure 12). The three components are as follows:

- A research and development model and supporting framework to function as a generator, magnet, conduit, clearinghouse, and database for good ideas.
- A modeling, simulation, and analysis component which contains a rigorous analytical capacity to evaluate and assess the improved performance, contributions, and associated costs that promising good ideas might have on large-scale logistics systems.
- An organizational implementation component which then enables the transition of promising concepts into existing organizations, agencies, and companies by providing training,

education, technical support, and risk reduction or mitigation methods to reduce implementation risk.

These three components serve to accomplish the following:

- Encourage and capture a wide variety of inventions
- *Incubate* those great ideas and concepts within virtual organizations to test, evaluate, refine, and assess their potential costs, system effects, and contributions in a nonintrusive manner
- Transition those most promising ideas and concepts into actual commercial or governmental practice

Hence the term innovation is deliberately in the center's title to express the notion of an engine for innovation to support major transformation endeavors in the government and private sectors driven by an increasingly recognized necessity for change.

These four modeling approaches—multistage optimization, dynamic strategic planning, risk management, and program development—should be used in unified and complementary ways to constitute a dynamic strategic logistics planning (DSLP) capability. DSLP can take, as input, both the empirical evidence of ongoing operational evidence (real world results) and also the potential contribution of new opportunities derived from an engine for innovation (synthetic results), and then guide (as output) logistics transformation toward strategic goals and objectives: an efficient, increasingly effective, yet resilient global military supply network. DSLP constitutes the analytical architecture needed to sustain continual improvement for logistics transformation (see Figure 13).

Collectively, CILS and DSLP have the potential to accelerate the process of management innovation by building a capacity for low-risk experimentation using a credible, synthetic environment. This cycle sustains continuous improvement through a deliberative process of incremental innovation achieved through experimentation, prototyping, and field testing.

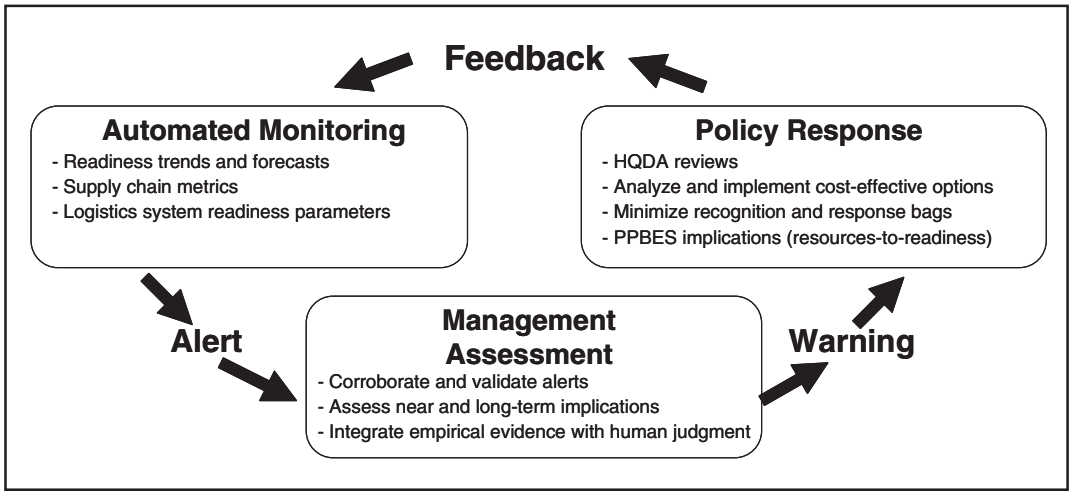


Figure 11. Logistics Readiness and Early Warning

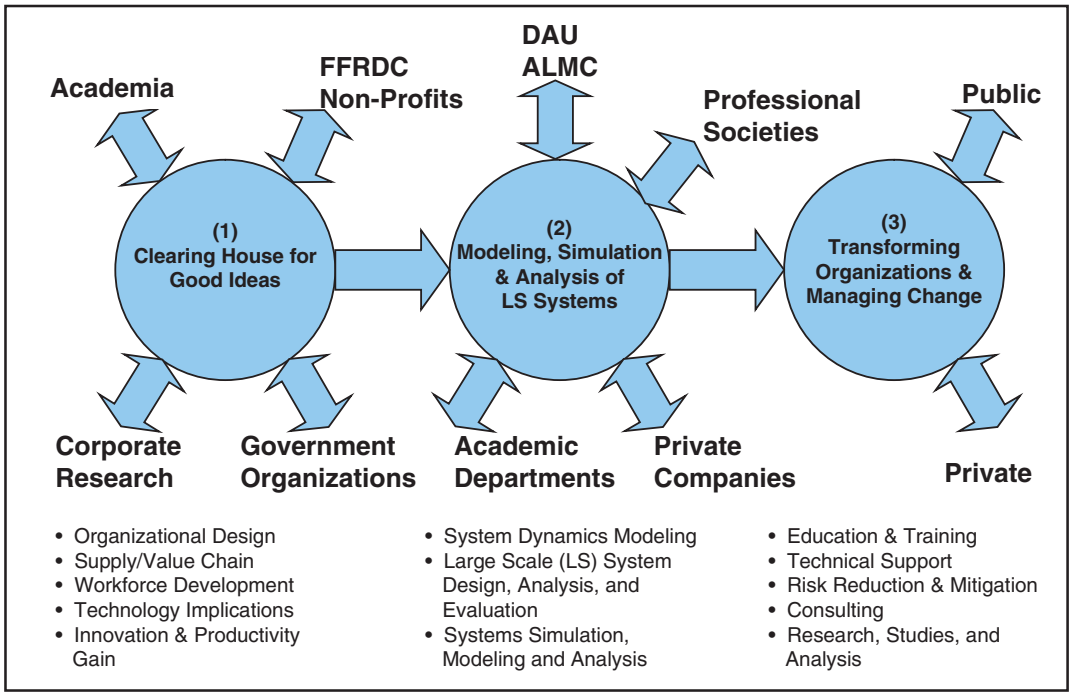


Figure 12. Center for Innovation in Logistics Systems

Final Thoughts

Tactical units in the US Army are renowned for pioneering and refining the after action review concept as a continuous learning method to surface, diagnose, and correct deficiencies in order to improve performance and sustain operational excellence. Yet comparable diagnostic effort has not been prevalent at strategic levels within the institutional Army bureaucracy. Since analytically rigorous diagnosis, understanding, and response on management issues are not routinely performed to uncover ground truth and learn from mistakes, reactive firefighting has been the standard response to visible symptoms. Army logistics management has become sclerotic.

As with any complex, large-scale systems challenge, key implementing concepts will be essential to ensure a successful Army logistics transformation endeavor. These organizational, analytical, information systems, technology, and management concepts should all be guided by a clear understanding of the

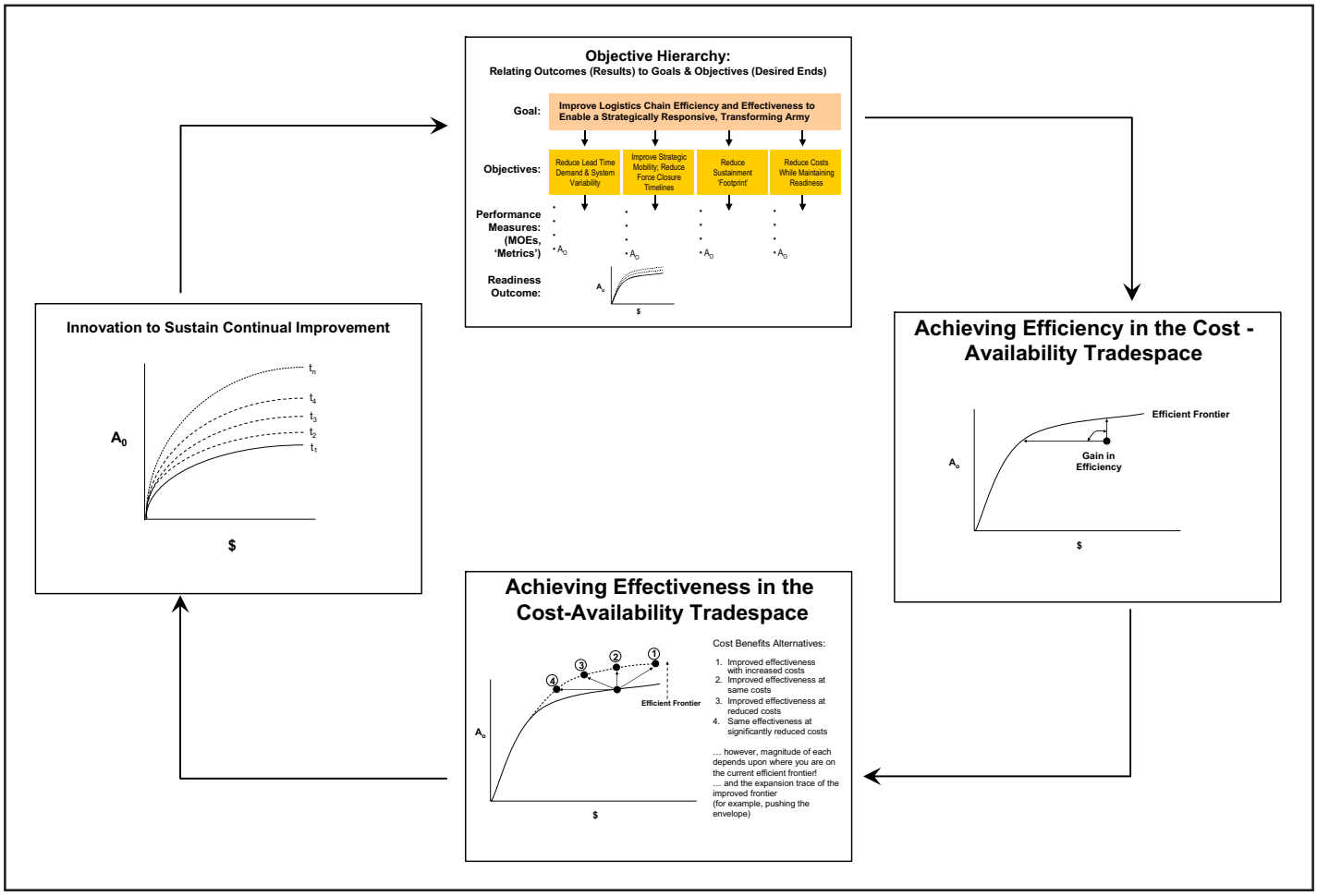


Figure 13. Sustaining Innovation While Linking Execution to Strategy

ultimate purpose for which the enterprise exists—an organizational vision for the future and a supporting strategy to realize the vision (see Figure 14).

This strategy must focus the effects of transformative change upon capabilities-based, readiness-oriented outcomes. The development of strategic planning and management frameworks are also essential to enable learning within organizations. Transformation will indeed require disturbing existing cultural paradigms, causing an inevitably disruptive period of significant change. Despite the inexorable advance of technology, it will be improved management and decision support systems that ultimately enable innovation potential to be realized. Finally, this endeavor should embrace that of a learning organization. This will be a crucial enabler for sustaining continuous improvement.

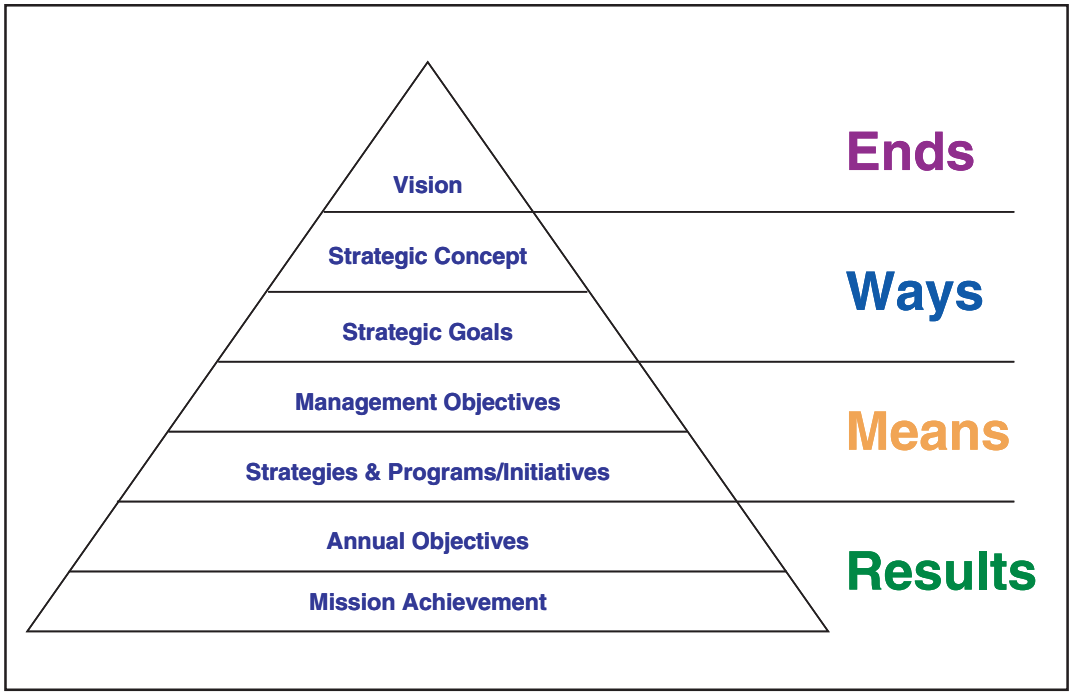


Figure 14. Logistics Transformation Framework—Linking Strategy to Measurable Results

We hope this endeavor will serve as a catalyst for an intellectual and professional resurgence in military logistics systems analysis. We are certainly encouraged by our empirical

research results which continue to reinforce and corroborate many of the intuitive concepts and ideas presented in this article. Consequently, we have engaged the larger military operations research and professional logistics communities and continue to encourage the participation of all those interested to collectively pursue this enormous challenge.

***Greg H. Parlier**, PhD, was the senior operations research/ systems analyst on active duty when he retired as an Army colonel. The project described in this article was initially undertaken in 2002 when he was assigned as Director for Transformation at the US Army Aviation and Missile Command, Redstone Arsenal, Alabama.*

Military Logistics and the Warfighter

I think we can all agree there is a relationship between the function of military logistics and the warfighter. What is that relationship, and is it correctly defined? In the early 1960s, there was a stated relationship between logistics and the weapons systems: military logistics "support" the weapons system. At that time, the subject of military logistics was fairly new and, with little ongoing research, very slow in providing greater *understanding* about it. Therefore, during that period, this definition of relationship seemed appropriate. It was not until the late 1970s that several advocates of military logistics came to the realization that logistics *support* of the weapon system was actually creating and sustaining warfighting capability. This warfighting capability was provided to the combat forces in the form of continuing availability of operational weapon systems (the tools of war). This new awareness set up another definition of the relationship: *military logistics creates and sustains warfighting capability.* While many heard the words, few realized their implications.

The level of warfighting capability that logistics provides the combat forces determines the extent to which war can be waged. This, in turn, limits and shapes how the war will be waged. Warfighting capability is *embedded* in the design of all weapon systems. Advancing technology increases speed, range, maneuverability, ceiling, and firepower, all of which provide more lethal and accurately guided munitions, stealth, and other offensive and defensive warfighting capabilities. They will be embedded into the design of future weapon systems. It is the weapon systems that contain the warfighting capability of military forces. The strength of military forces is no longer measured by the number of men *under arms*. Today, military forces are measured by the number—and warfighting capabilities—of their weapon systems. The Department of Defense has yet to adequately define and manage the total logistics environment (those activities and resources required to create and sustain warfighting capability). While it is said that armies travel on their stomachs, what is usually left unsaid is they perform on the basis of their logistics competency.

Today, as most of you are aware, we have another, more recently defined relationship: *military logistics supports the warfighter*. We know military logistics creates and sustains warfighting capability. We can assume the warfighter fights wars. It would, therefore, appear reasonable to suggest that in order for one to be a warfighter (a pilot in this case) he or she must have the capability to wage war. While weapon systems are designed and created to wage war, people are not. Therefore, in order to become warfighters, pilots must be provided with some level or amount of warfighting capability. I would submit that by providing the pilot with an operational weapon system, which allows him or her to utilize its warfighting capability, *military logistics creates the warfighter*. It does not *support* the warfighter; it *creates* the warfighter. This transformation occurs when a checked-out pilot starts the engine. At that point, the pilot is in control of the weapon system and its warfighting capability. The pilot is now the warfighter. Without the warfighting capability, which the weapons system provides, a pilot is a pilot.

Military logistics creates and sustains warfighting capability; by doing so, military logistics creates and sustains the warfighter.

Colonel Fred Gluck, USAF, Retired

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Leaning the DoD Supply Chain: the DoD Activity Address Code

Jay Barber, Global Logistics Support Center, USAF
Michael Werneke, Global Logistics Support Center, USAF
Kevin P. Duffy, PhD, Wright State University

Introduction

Information is the key to enabling supply chain design and performance. Accurate shipping and billing addresses are vital to the transportation segment within the supply chain; these addresses assure that products get to the right place, at the right time, and at the right cost. This is true for all supply chains, but even more so for the Department of Defense (DoD) distribution system. Not only does the DoD have fixed locations around the world to where supplies are shipped, but the DoD also ships to combat operations that continually change their locations.

Every DoD organization, including those in combat zones, has an address to receive mail and materiel. To manage this information, the DoD relies on a 6-digit code called a Department of Defense activity address code (DODAAC, pronounced "doe-dack") which represents an organization's physical address. Currently, the Air Force assigns and maintains over 9,000 DODAACs. This article documents the reengineering of an antiquated DODAAC maintenance process by applying Lean techniques.[1] Modern Web technology and the utilization of Lean concepts has enabled the development of a system that not only improves efficiency and reduces man-hours of processing time, but also provides tools for tracking information that have been impractical in the past. We discuss the history of DODAACs, their importance to DoD and Air Force activities, how the DODAAC system used to work, and what changes were required. We then discuss the redesign, development, testing and implementation of the new system. We conclude with a discussion of how the Air Force supply chain will benefit from using the new DODAAC Web Management System.

The warfighter must have visibility of all logistics processes to effectively engage in combat in the dangerous, resource constrained, and remote locations where they are deployed. Creating systems that are able to provide the instantaneous information required is essential for effective operation in war zones.

Lean Initiatives in the Supply Chain

The introduction of manufacturing systems had a profound impact upon workers, organizations, and life. These systems were set up to speed parts and raw materials through the manufacturing process. In turn, less expensive production methods resulted in the production of less expensive goods for consumers. As an added bonus, organizations realized huge profits. However, many of these manufacturing systems were laid out without giving thought to the process as a whole, or how the parts or pieces of the process interacted in order to produce a finished good. In an effort

to keep the manufacturing process moving, firms often would accumulate large amounts of parts and other inventory. The notion behind holding vast amounts of inventory was that of fully utilizing manufacturing tools and the firm's labor pool. Fully utilizing tools and labor would result in producing as much of a product as the firm was capable of producing. Unfortunately, this perspective did not consider the costs associated with inventory or its related carrying costs. The availability of excess labor and excess inventory, while enabling production to carry on within a manufacturing facility, translated into a cost to the firm which did not add value to the finished product (did not add value to the end customer).

In contrast, Lean initiatives, as applied to the manufacturing process, are intended to improve business by focusing on the elimination of waste. When Lean principles were adopted within manufacturing, more attention was given to factors such as how a chain of processes worked together, or how a process could be broken down into a rearranged series of tasks or steps.

Lean principles were originally adopted by organizations in an effort to remove waste and revitalize manufacturing processes, with hopes of achieving productivity gains seen in Japanese companies. Grant states that "Lean manufacturing was developed in Japan to eliminate waste in manufacturing processes."[2] An implementation of Lean principles strives to eliminate waste; both physical waste (excess inventory holdings) as well as process waste (removing excessive processing time and unnecessary processing steps from the firm's value chain). Underlying the application of Lean is the discovery that while processes may differ from manufacturing to service companies, and from one type of process to another, processes seem to suffer from the inclusion of unnecessary or wasteful steps. Taking an approach of standardizing process design aids in uncovering and eliminating many of these redundant or wasteful steps.[3]

Manrodt, Vitasek, and Thompson[4] note that their research has pointed them toward six attributes which are vital to building a Lean supply chain. These attributes are as follows:

Article Acronyms

AFB – Air Force Base
AFMC – Air Force Materiel Command
DAASC – Defense Automatic Addressing System Center
DoD – Department of Defense
DODAAC – Department of Defense Activity Address Code
DODAAD – Department of Defense Activity Address Directory
HQ - Headquarters
ICP – Inventory Control Point
LOT – Office Symbol for Distribution Office
LSO – Logistics Support Office
MAJCOM – Major Command
MILSTRIP – Military Standard Requisition and Issue Procedures
SME – Subject Matter Expert
SP – Service Point
TAC – Type Address Code

- Improved demand management
- Waste and cost reduction
- Process standardization
- Industry standards adoption
- Cultural change agent
- Cross enterprise collaboration

Improved demand management is an organizational focus on moving toward a *pull* supply system, rather than a *push* system. Briefly, a pull system revolves around customer demands (initiated when a customer places an order) rather than a manufacturer pushing goods into the system. Waste and cost reduction work hand-in-hand within a Lean system, rather than competing with one another. This is to say that cost reduction is not more important, as a system goal, than is reducing—or eliminating—waste. Waste can take the form of time, excess inventory, or can be found within organizational processes. Often, the authors note, when waste is reduced or eliminated, this reduction may be accompanied by cost reduction. Importantly, though, the authors note that the focus should remain one of reducing waste. They caution that focusing too sharply on cost reduction may "lead a firm down a suboptimal path, as not all waste can be easily tied to costs."[5]

Process standardization requires the firm to promote the standardizing of processes across the firm, with the intention of directing the process flow toward the chain's most efficient points. Further, they note that organizations wishing to differentiate themselves on the basis of proprietary workmanship may actually impede the smooth and efficient flow of work and processes, especially when materials and products cross country and organizational borders.

The notion of Lean being involved in cultural change stems from the age-old problem of resistance to change. The authors note[6] that one obstacle to implementing Lean principles is that these actions must be undertaken by people—people who often question why the tried-and-true methods of accomplishing tasks is no longer viewed as optimal. In these cases, actively promoting Lean through change management may be valuable for the firm. Kumar[7] states that organizations may wish to involve users and other employees in the project, as this will foster a sense of ownership. Finally, and importantly with respect to the supply chain, is to emphasize the notion of working with partners in bringing value to the customer, rather than suboptimally embracing a view which extends no further than the organization's boundaries.

While the practice of Lean manufacturing has been around for a while, the notion of applying Lean principles to the supply chain is a newer concept. Grant notes[8] that "most businesses have yet to apply Lean thinking to service and transaction processes."

This article examines the efforts to introduce Lean to the Department of Defense (DoD) supply chain. A survey conducted by Manrodt, Vitasek and Thompson[9] discovered that although Lean principles and concepts are being applied to the supply chain across numerous organizations, these principles are slow to be adopted in nonmanufacturing organizational settings. Additionally, the researchers note that the application of Lean can result in behavior or procedural changes within organizations. These necessary changes often present a barrier to the adoption and application of Lean. (The authors cite the

common anecdote of "we've always done it this way" as an example of resistance to change.) Importantly, the DoD is seen as an enormous organization, and an organization which is steeped in the traditional: the DoD encompasses ways of doing things which apply to supplier selection, organizational processes, and rigid hierarchical chains of command.

Thus, the implementation of Lean principles into the DoD supply chain grants an extraordinary opportunity to examine a Lean implementation from two different perspectives. The first is that of applying Lean to a nonmanufacturing organization. The second perspective is to view attempts to implement Lean in a rigid organizational setting. Our hope is to gather lessons learned from the implementation which, in turn, may assist other nonmanufacturing organizations, as well as other hierarchically structured organizations in their considerations of whether or not Lean initiatives are worth pursuing within their own organization.

The DODAAC within the DoD

For nearly 50 years, the DoD has relied on a standardized logistics system to manage the requisition and supply processes necessary to support worldwide armed forces operations. This program, known as Military Standard Requisition and Issue Procedures (MILSTRIP, DoD 4000.25-1-M) was designed in an era of mainframe computers and punch cards. Since data entry was restricted to 80 characters of data per card, the program relied heavily on coding of information. These codes are delineated in written manuals, regulations, or instructions. Although the DoD is working on modernizing this system, MILSTRIP is still in use today and still relies on *coded* information.[10]

One code is the DODAAC. The DODAAC is a six-digit code that represents shipping, mailing, and billing addresses for DoD locations throughout the world.

The Defense Automatic Addressing System Center (DAASC), located at Wright-Patterson Air Force Base (AFB) houses the data base that maintains the addresses for the DoD. This database is called the Department of Defense Activity Address Directory (DODAAD). Governed by DoD Manual 4000.25-6-M, this publication delineates responsibilities for each branch of the military and various other government agencies that supply material to the DoD and require DODAACs. Each of these organizations has an office called a *service point* to maintain their codes and addresses and input the information into the DODAAD.

The Air Force service point is located within the 401 SCMS/Distribution Flight at Wright-Patterson AFB. This service point maintains over 9,000 military and contractor DODAACs located throughout the Air Force. The office works with customers worldwide to establish new Air Force addresses. Prior to the reengineering effort, new addresses were accomplished through a series of complex and outdated methods including an Air Force Materiel Command (AFMC) legacy data system (D035T, developed in the 1980s), a Web site developed in 1995, and a network of military and civilian employees who approve new codes and address changes for their Air Force major command (MAJCOM). For example, Headquarters AFMC has four persons assigned the task of maintaining the DODAACs for all of the command—an organization with over 78,000 people.

Background

DODAAC Essential to the Air Force Supply Chain

Whenever an Air Force organization needs stock listed material (material that has been designated with a national stock number) to support their mission (for example an aircraft part) their supply system (Standard Base Supply System) generates a DoD requisition which is routed to the appropriate inventory control point (ICP). An item manager of the part determines from where to source the request and generates a material release order to have the item released from stock, or ordered from a vendor, and shipped to the customer. A DODAAC identifying the organization submitting the requisition is necessary before the requisition can be processed by the ICP. Once the material is released for shipment, the DODAAC is used to indicate where the material is to be shipped and is included in the transportation control number used to track the shipment through the transportation pipeline. Without a DODAAC included in the requisition, none of this could take place.[11, 12]

DODAAC Requirements

Although the DODAAC is a simple 6-digit code and the data behind the code is relatively straight forward (addresses), the information associated with a DODAAC's application within each Service and agency can be complex. The rules directing how addresses are developed and displayed in the data base are standard throughout the DoD. For example, each DODAAC will have a corresponding clear text address that will consist of a type address code (TAC) 1, 2 or 3. A TAC 1 address represents where a unit wants mail and mail-like material (US mail and possibly small parcel delivery) delivered. A TAC 2 address is where a unit wants freight delivered (normally larger than 150 pounds), and a TAC 3 is an invoicing address. Many times only a TAC 1 address is required as the unit may want both freight and mail delivered to the same location. Mail to overseas locations will usually go to an APO (military post office) and freight will go to a separate location with a street address requiring both a TAC 1 and TAC 2 address. International addresses have a variety of differences, so DAASC has developed a standard address format so all Services make their addresses look the same.

To keep each agency and military Service's DODAACs unique and separate from each other, the DoD has designated the first letter of the DODAAC to represent each Service and agency. The Air Force is restricted to codes that begin with E, F, and J. Although there are only three sets of codes available to the Air Force, there are thousands of combinations of numbers that can be created. All the other military Services and DoD agencies that require a DODAAC have been assigned their own unique codes. An "A," for example is for Army. The Air Force cannot assign any DODAAC that begins with an A. As long as the DODAACs begin with E, F, and J, the Air Force has been free to develop its own policy concerning format and use of the codes.

Air Force DODAAC Requirements

Over the years the Air Force DODAAC policy was developed to use the codes for purchasing and shipping various types of commodity (engines—FExxxx, munitions—FKxxxx, fuel—FPxxxx), types of product (computers—Fuxxxx, clothing—FSxxxx), types of service (base library—FLxxxx, dining halls—FTxxxx), and types of process (base supply—FBxxxx, ship to

only—Fyxxxx). In addition, F series DODAACs apply to military, E series DODAACs apply to Air Force contractors and J series DODAACs are used to supply a range of maps and flight publications to flying activities throughout the Air Force. To manage DODAACs for all these different purposes takes a large network of persons to provide the knowledge of how and why an Air Force DODAAC will be assigned (Air Force Manual 23-110, October 2005; Air Force Instruction 24-230, August 1996).[13, 14]

Air Force DODAAC Process Evolution

The DODAAC assignment process starts with an Air Force military unit or Air Force contractor identifying the need to have a new DODAAC assigned or to change or update an existing DODAAC. This could mean they relocated an office, formed a new organization, or in the case of contractors, have a new contract with a new manufacturing facility; all of which might require a new DODAAC to identify their new address. This has been especially critical in recent years since the country has been involved in Afghanistan and Iraq and has established many new addresses.

Past Practices

To get a DODAAC assigned, the initiator submitted a request (in the form of an e-mail, fax, or phone call) to the DODAAC monitor assigned to their parent MAJCOM for approval. When the MAJCOM DODAAC monitor determined they agreed with the request, they forwarded it to an Air Force control office (a subject matter expert [SME] for the type of equipment or material that would be purchased with the pending DODAAC) for their approval. Once the SME was satisfied with the request, it was forwarded to the Air Force service point. Once the service point agreed with the request, a code was assigned and forwarded to the DODAAD. Once established, the code was then available to be used for requisitioning and shipping material. This process could take as little as 2 to 3 days, but many times took much longer depending on the speed of the command monitors and the control offices. Sometimes it would take as much as 8 to 10 days (or longer) depending on availability of personnel within the approval process (vacations, sick days, business trips, and military deployments could delay request processing). Sometimes requests were lost altogether. In this case it was up to the originator to track down and locate his/her request. Although this process had issues, it was much better than processing computer *punch-cards* to the mainframe that the service point relied upon for many years. That process took as long as 30 days to complete.

Before reengineering, most steps in the DODAAC request and approval process were manual. After the requests from customers were processed and validated, personnel in supply chain management squadron would enter the data (two employees—full time) from the request into an Air Force legacy computer system (D035T) which sent the information to DAASC in a daily batch process which was then updated to the DODAAD. Once each day DAASC would then broadcast a data feed back to D035T to update the DODAAD information for use by the Air Force. D035T then became the Air Force's primary source for providing DODAAC data to other Air Force data systems.

A New Process Sought

As this process matured in the mid-1990s, a new DODAAC search process was desired. DAASC had a DODAAC program to display the addresses associated with a DODAAC, but one could not use any other information to create a search. For example, if one knew the zip code where the DODAAC was located, but didn't know the DODAAC, there was no way to find the DODAAC. A solution to this problem was to build a Web site that could take the information provided from DAASC each day to D035T, manipulate it, and create a search engine available to everyone in the Air Force. This was the beginning of the current process.

Several years after implementing the DODAAC Web site with its improved search capabilities, a cut in manpower (eliminating one of the full-time positions used to make all the additions and changes) LSO/LOT allowed the MAJCOM monitors the ability to use the Web site to make changes to addresses for DODAACS within their command. This was not well received since it pushed workload onto requesting offices. Additionally, there were many mistakes made in the data entry, and the service point office had no visibility as to what changes were being made. Calls from the field asking why shipments were not getting to them would generally uncover a mistake in their shipping addresses (because a MAJCOM monitor put in an incorrect address). The problem was corrected, but it took a lot of time to find the problems. Further, this created a bad situation for the customer, potentially causing the loss of valuable equipment intransit. To combat this problem, the service point office developed a feedback loop to provide visibility of any changes the MAJCOMs were making. Although it was after the change was made, it allowed for resubmission of another change if an entry was incorrect.

Small improvements were continually made to this part of the process but were still tied to D035T for DODAAC additions and deletions and the Web site for making changes. Figure 1 demonstrates how the system was working at the beginning of the project. All requests were supposed to be going to the MAJCOM monitor with new and delete transactions going to the Air Force Service point for entry into the DODAAD through D035T. In reality all of the add and delete requests, and many of the changes to existing DODAAC transactions were being sent to the Air Force service point. They had to be forwarded to the appropriate MAJCOM monitor for them to work. When the process was reviewed for this reengineering project investigators quickly found the existing process to be cumbersome, slow, somewhat disorganized, and labor intensive.

Air Force DODAAC Process Review

The DODAAC process review was initiated by several events; namely, the *War on Terror* and the increasing number of humanitarian relief operations. This elevated operation tempo identified a problem with being able to quickly add, change, and delete Air Force DODAACs as locations were established, closed, and relocated to support field troop movements. In working this process review, Lean principles were used as a guide.[15] Realizing the difficulties we had with the existing process we determined this would be a good project to reengineer.

Problem

When personnel working on the project began to brainstorm the limitations of the existing process flow, they identified many problems that affected the customer and the infrastructure in place to develop and maintain Air Force DODAACs. The following were the primary process problems identified:

- The customer did not have a consistent method to submit requests.

- The system in place was not customer oriented (user friendly).
- There was no customer feedback or tracking system.
- The system was labor intensive and somewhat unorganized.
- Air Force DODAAC data had to be updated manually.
- DODAAC paper files were cumbersome.
- D035T system changes were impractical.

Goals

Once the main problems with the DODAAC process were identified, the following goals were established as a guide through the reengineering process:

- Improved customer service
  - Ability for customer to figure out how to get a DODAAC assigned without added input from anyone—totally self-help
  - Faster and easier process for the customer
  - Process would be the only way to get a DODAAC—one-stop shopping
  - Customers would have visibility of the progress of their DODAAC requests
- Improved process control
  - Minimize workload for the MAJCOM monitors and the Air Force service point
  - Eliminate duplication in data entry
  - Delegate workload
  - Create a system that was less susceptible to *gaps* in the process (evaluators and approval authorities missing from the system)
  - Ensure more consistent information was passed through the system
- Administrative
  - Create metrics that would measure the process, locate bottlenecks, and help provide the basis for continual improvement
  - Eliminate paper files
  - Ensure traceability and accountability for all transactions
  - Improve training for those involved in the process

Limiting Factors

As with any new project there are constraints in trying to move from conception to implementation. No additional funding, personnel, or new equipment procurement could be devoted to this reengineering project (the project was started after the fiscal year and no funding requirements for this project had been included in the organization's budget request). Without funding, creative solutions and time management techniques had to be used to move this project from conception into reality.

Solution

DODAAC service point technical specialists were consulted, as well as a computer programmer to develop a flow chart of the process. Current Web technology, coupled with the programmer's knowledge of Web-based database management would permit the building of a process that would let the customer create the original record, and then send that record through an approval process without duplicating the data. The Web site should be simple to understand and display everything the customer would need to request a new DODAAC or change an existing one. Figure 2 demonstrates the basic process flow. The customer would access the Web site and select an operation. Once a form was displayed, the customer would complete the form and submit it. The computer would route the request to the MAJCOM monitor. Request approval required the monitor to press a button which sent it to the next person in the approval process, the control office. If the MAJCOM monitor disagreed with some part of the request, a rejected request could be returned to the customer for rework. This process would be repeated until the request made it to the Air Force DODAAC service point. There a new DODAAC request would have a DODAAC assigned and would be sent to DAASC for loading into the DODAAD. The process design was straightforward and was simple in concept. Building it was a lot harder.

A team of experts, including three internal DODAAC technical specialists, a computer programmer, and management was assembled; the team worked this project in addition to their normal workload. The team would meet for short brainstorming sessions (1 to 2 hours) two to three times per week. At first the meetings were used to develop the structure of the Web site. As the project progressed, the meetings were used to review previous work, demonstrate the work, and discuss what would be done after the meeting. In this manner all team members were kept on track. These meetings were also used to sort out technical problems, find alternatives, and redirect the programmer's activities. As the project progressed it went through the following steps:

- Mapped the new Web site and data management system
- Developed the Web site *framework*
- Developed the Web site structure—what the customer sees

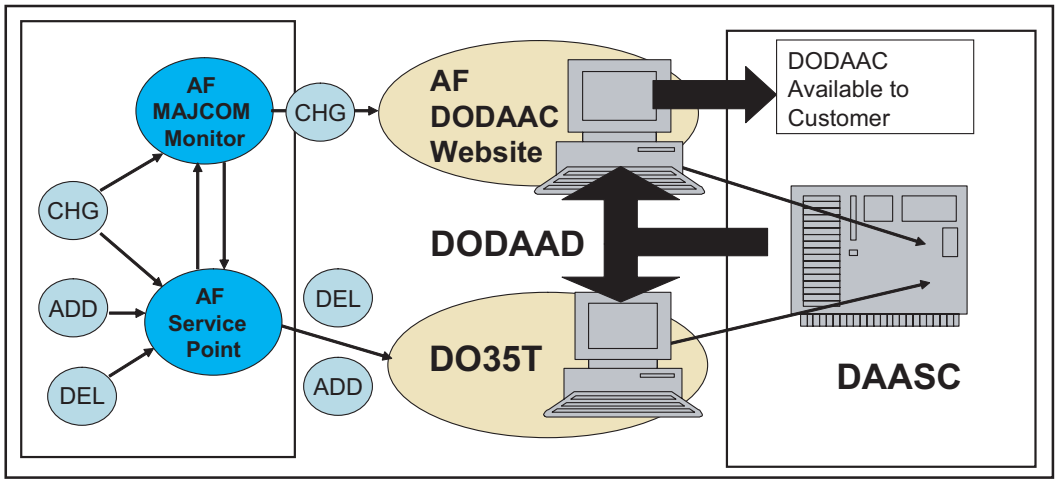

Figure 1. DODAAC Process Before Reengineering. Notes: the customer would submit his or her requests by phone, fax, or e-mail to either the Air Force service point or the MAJCOM monitor. The service point and the MAJCOM monitor would collaborate on the information and determine which office would submit the request. Most DODAAC changes were submitted by the MAJCOM monitor through the Web site and all the new and deleted DODAACs had to be submitted through D035T.

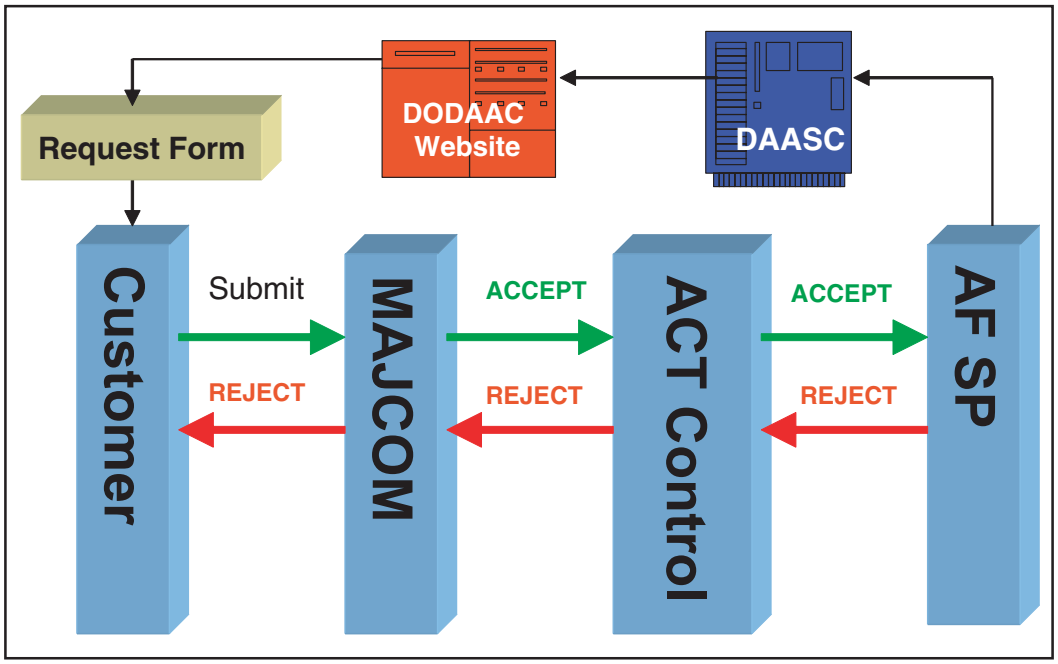

Figure 2. The DODAAC Web Management System

- Developed the supporting data tables and drop-down help data
- Developed the *flow* process
- Internal operability testing and review
- Data connection to other systems
- Acceptance and approval for using
- Prototype demonstration

The service point office hosted a DODAAC workshop at Wright-Patterson AFB when the new system was developed enough to demonstrate and validate the process. All MAJCOM monitors, control offices, and other SMEs were invited to attend. The agenda included introducing the system's capabilities, showing attendees how they would use the system, and most importantly, get feedback from the audience to allow for any last minute changes to the system before implementation.

The meeting provided valuable discussion and recommendations, specifically identifying ways to improve the system and make it more user friendly. This feedback was especially useful as it validated the system design and allowed for *buy-in* from the workforce. Some of the important items changed as a result of feedback from the meeting include the following:

- Add help note for deployed units under MAJCOM drop-down box on request form
- Develop *Reroute* system for requests that get submitted to the wrong MAJCOM monitor
- Add Headquarters Air Force on MAJCOM drop-down box
- Add link to MAJCOM monitor list in e-mail receipt back to requestor
- Add *No Special Characters* message to request form to alert requestor not to use (*, /, -) in address lines
- Add confirmation number to submission page for new requests
- On MAJCOM monitor, control office, and service point request view pages, add a link to requestor contact information in case they have questions about request
- Change canned responses to checkboxes on request view forms
- Add selection for City/State change to *Line 3, Line 4, No Change* on TAC 1 on DODAAC change form (like TAC 2 has now)
- Make rationale required field on change/delete form
- Put in *Are You Sure* page on closed/delete account form
- Make WPOD and APOD a drop-down box of selections to ensure they choose correct one; add help button.
- Set up dynamic validation report page and develop export to Excel feature
- Build requestor change/edit page for rejects from MAJCOM back to requestor
- Setup 24-hour tracking system
- Develop metrics of tracking information

Some very significant changes were developed during this validation trial run. Other important topics covered during the meeting were to brainstorm how to structure the annual validation process and how to do the live testing of the system. Following the meeting, two final steps included that of performing adjustments to the process, and the crucial step of live field testing and validation.

Testing the new system would be challenging because a complete test could not be run without turning off the existing system (the DODAAC Web Management System was hosted on an Air Force server that resided inside the Wright-Patterson AFB network firewall). Further, access was through one portal—there was no way to run the test while the old system was still functioning. MAJCOM monitors were informed of the shutdown to ensure they had all required work up to date, since only *emergency* DODAAC changes would be processed during the 10-day system shutdown. Manual updates in D035T were performed on an as-required basis.

The test was scripted by completing a DODAAC input for each MAJCOM monitor in our system. At a designated time each MAJCOM processed the information they were given. The flow of information was measured. After the first test, only 60 percent (approximate) of the information had been received. The system appeared to be working properly, but some of the MAJCOM monitors did not process their information correctly.

A second test was run to assure the system was working as intended and that the problem was not with the program. The second test was a great success. All of the information in the second test flowed properly and the Air Force DODAAC Web Management System was made available for Air Force use.

Implementation Results

The system is a major improvement. As soon as the DODAAC Web Management System was implemented one could tell it

would serve the Air Force as it was intended. Other than some minor glitches that were fixed quickly (usually within hours), the system has performed well.[16] The system has allowed DODAAC processing time to be reduced from an average of 4 to 5 days to its current average of 2 to 3 days.[17] The system has reduced administrative workload (waste) at least 75 percent system-wide (metrics are being developed to measure this accurately), provides accurate electronic records, and provides a single, precise method to manage DODAACs for the Air Force.

Supply Chain Improvements

The system was designed, developed, and implemented to follow the principals outlined by James Womack and Daniel Jones, in their book *Lean Thinking*.[18] More specifically, the goals included the need for the following:

- Create value from the customer's perspective
- Determine and improve the *value stream*
- Create *flow* through the system
- Create *pull* processes
- Strive for *perfection*

This *Lean thinking* allowed the process to be rebuilt from the customer's point of view. The existing system had not been set up to *guide* the customer; this was a main focus in designing the new system. Next, considering the process as one part of the value stream, the new system was built with the ability to replace the aging legacy system as the DODAAC data warehouse for the Air Force. This approach built in flexibility to store, manipulate, and use the DODAAC data in a manner beneficial to the entire Air Force.

To improve flow, the process to create or maintain a DODAAC is now streamlined. Instead of multiple ways to get the job done, the improved system has only one way to process a DODAAC. This eliminated many wasteful process steps, reduced redundant effort, and organized the data to come close to providing the customer same-day service.

The new DODAAC development and maintenance process is a true pull system. The customer is no longer responsible for figuring out what their request should consist of, what medium to use to communicate that request, and where to process their request. Instead, the system pulls the customer's request through once the customer places their order. The system triggers work at each approval point by an e-mail to tell the evaluator they have a request to review and the system measures each step of the process. Once the customer submits a request they can follow the approval process simply by visiting the Web site and using the Tracker system. From the Air Force supply chain perspective this helps the customer get their DODAAC assigned and updated faster than ever. It allows the customer to order material faster and reduce the stress in establishing a new address when speed may be critical.

Conclusions

The last Lean principle—perfection—is an ongoing process. This new system is not *finished* and may never be, since the Air Force is constantly changing. The old system was built around a legacy computer system which prohibited even small changes. The new system is very flexible to changes. Table 1 compares all DODAAC processes before and after Lean thinking was initiated and applied.

Discussion and Lessons Learned

From the start of the DODAAC system process improvement the team was focused on adding value for the warfighter. Nothing is more frustrating than being deployed in a remote and hostile location and not being able to accomplish a mission because of an inability to procure needed supplies. Under the old system it could take 3 or more days to get an Air Force DODAAC validated and loaded into the DODAAD. During this time the warfighter was waiting, unable to order the supplies required to accomplish or sustain the mission. The new system process will establish a new address in the DODAAD within 1 or 2 days. By working from the customer's perspective through the entire value stream, the team was able to provide better visibility of the process, establish metrics to control the process, improve overall data quality, and reduce total processing time using the same resources. Improving logistics support by 24 to 48 hours will continue to ensure our warfighter has a battlefield advantage.

There were a variety of lessons to be learned from the successful implementation of Lean principles. First and foremost of these is that the system is a success. This success is largely due to the formal aspects of the system itself. Committing the entire process to the system forced entry of data into the system—data did not get lost or otherwise go astray. The system aspects of the DODAAC system permitted rapid data entry, error detection, and error correction. Ultimately, the speed of the system facilitates the goals of the organization, individual units, and of those waiting for supplies.

Further, the system enabled streamlining of the entire process. In turn, this streamlining added tremendous visibility to the project, as potential users (DODAAC requestors) were following development and implementation efforts. Frequent meetings were held with users, both to provide progress reports and to seek their input into the system. These meetings had an unexpected benefit of strengthening user buy-in to the system.

One unexpected bonus only appeared following implementation of the system. In response to an Air Force Audit Agency finding, the system was modified to include a contractor validation page (and supporting process) to improve the ability to monitor DODAACs created for contractors. Before the modifications, it was not possible to monitor when to delete contractor DODAACs. Unless deletion had been requested by the contracting offices, there was no way to recognize an unneeded DODAAC and to act accordingly. In turn, this gap in information would permit contractors to order material from the defense supply system after a contract had expired. The modified process enables the contracting office to cross reference contracts to DODAACs and DODAACs to contractors. When fully implemented, this feature will allow for determination of when to delete a contractor DODAAC. In this fashion, the information is serving to ensure the integrity of the underlying process.

The Lean initiative described in this article not only ensures process integrity, but also provides a significant image boost to a process which before had been haphazard. The DODAAC assists in collecting all required information, collecting all required approvals, and by identifying bottlenecks in the process, assures that the process completes in a minimal timeframe. The goals and objectives of the organization, as well as those of its customers, are better met through the implementation of Lean principles underlying the DODAAC system.

System Function	Original Process	Lean Process
Creates Value for Customer	• Request process not clear • Various request methods • Customer always confused by request process • No customer feedback • Slow process (3-5 days)	• More visual process • One stop shopping • Totally self help • Visibility of DODAAC request • Faster process (2-3 days)
Improved Value Stream	• No single request process • No clear request guidance • Multiple approval process • Multiple data entry points • Data re-entered several times • Approval process not concise • Unclear workload delegation	• Created clear request process • Eliminated wasted time in processing DODAAC request • Single Data entry point • Improved data accuracy • Reduced processing time • Reduced workload • Workload clearly defined • Eliminated paper files • Reduced process gaps
Created Flow Through the System	• Inconsistent request process • Input not consistent • No customer feedback • Uneven workload in system • Duplicate workload • Inconsistent data into system	• Developed one method to request DODAAC • Standard request forms • Data entered once • System routes requests • All transactions accomplished on Web site—no phone of fax • Approval process done online—read request, push button • All approval actions and communication on one page
Created Pull System	• Customer had to push request • System was slow to react to request • No method to notify approval process of request in system • Many gaps in approval process • Customer had to provide legwork to find request	• System activates only with customer order • Customers request automatically routed through the system • Email sent to next approval point • If request rejected, system reroutes • Feedback loop keeps customer informed of progress
Perfection	• System patched together • Unable to change legacy system • No standard process • No quality control in system • Difficult to develop knowledgeable staff • No measure of system performance	• Continually reviewing process for improvement • System improves training for those involved in the process Provides metrics to measure and improve the process • Locates and eliminates bottlenecks in process • Platform for continual update

Table 1. DODAAC Process After Lean Thinking Applied

DODAAC Web Management System Updates

In the time since the DODAAC system began, many improvements have been made to the system. One of the most significant was the alignment of Air Force data with that in the DODAAD maintained by DAASC. This major development allowed for the elimination of the daily batch process. Instead, DODAAC input is pushed to DAASC in real time. Instead of taking 1 to 2 days, a DODAAC change or addition can be input in minutes, allowing a unit to order material much quicker.

A second major improvement provides a way for the Air Force contracting community to validate and maintain Air Force DODAACs assigned to their contractors. Previously, contracting offices had no way to determine if their contractors had a need to keep assigned DODAACs. Now contracting offices can use this system to validate the contactors continued need for a DODAAC and delete DODAACs when the contract expires.

Notes

1. James P. Womack and Daniel T. Jones, *Lean Thinking*, New York, NY: Free Press, 2003.
2. Vince Grant, "Lean Six Sigma – The GUTs of Improvement?" *Management Services*, Vol 52, No 1, 2008, 22-23.
3. *Ibid.*
4. Karl B. Manrodt, Kate Vitasek, and Rich Thompson, "The Lean Journey," *Logistics Management*, Vol 47, No 4, 2008, 35-38.
5. *Ibid.*
6. Manrodt, et al, 2008.
7. Dinesh Kumar, "Beyond the Low-Hanging Fruit: Designing an Enduring Lean Supply Chain in the Consumer Packaged Goods Industry," *Industrial Engineer*, Vol 36, No 5, 2004, 44-48.
8. Grant, 2008.
9. Manrodt, et al, 2008.
10. DoD 4000.25-10-M, *Defense Automatic Addressing System*, Washington, DC: Government Printing Office, October 2003.
11. DoD Directive 4140.1, *Supply Chain Material Management Policy*, Washington, DC: Government Printing Office, April 2004.
12. DoD 4140.1-R, *DoD Supply Chain Material Management Regulation*, Washington, DC: Government Printing Office, May 2003.
13. Air Force Manual 23-110, *United States Air Force Supply Manual*, Washington, DC: Government Printing Office, October 2005.
14. Air Force Instruction 24-230, *Maintaining the DoD Activity Address Directory (DODAAD)*, Washington, DC: Government Printing Office, August 1996.
15. Womack and Jones.
16. Once in the first month of operation we had to take the system down for one day to fix a minor issue.
17. We are working on replacing the daily *batch* process with *real time* delivery to DAASC, which should give the system same-day service.
18. Womack and Jones.

Jay Barber *is currently a Transportation Specialist for the 401 Supply Chain Management Squadron at Wright-Patterson AFB, Ohio. At the time of the writing of this article, he was a student at the Raj Soin College of Business at Wright State University, Ohio.*

Michael Werneke *is currently Chief, 401 Supply Chain Management Squadron at Wright-Patterson AFB, Ohio. At the time of the writing of this article, he was a student at the Raj Soin School of Business at Wright State University, Ohio.*

Kevin P. Duffy*, PhD, is an Assistant Professor in the Information Systems Operations Management Department, Raj Soin College of Business, Wright State University. He completed his doctoral studies in Management Information Systems at Florida State University.*

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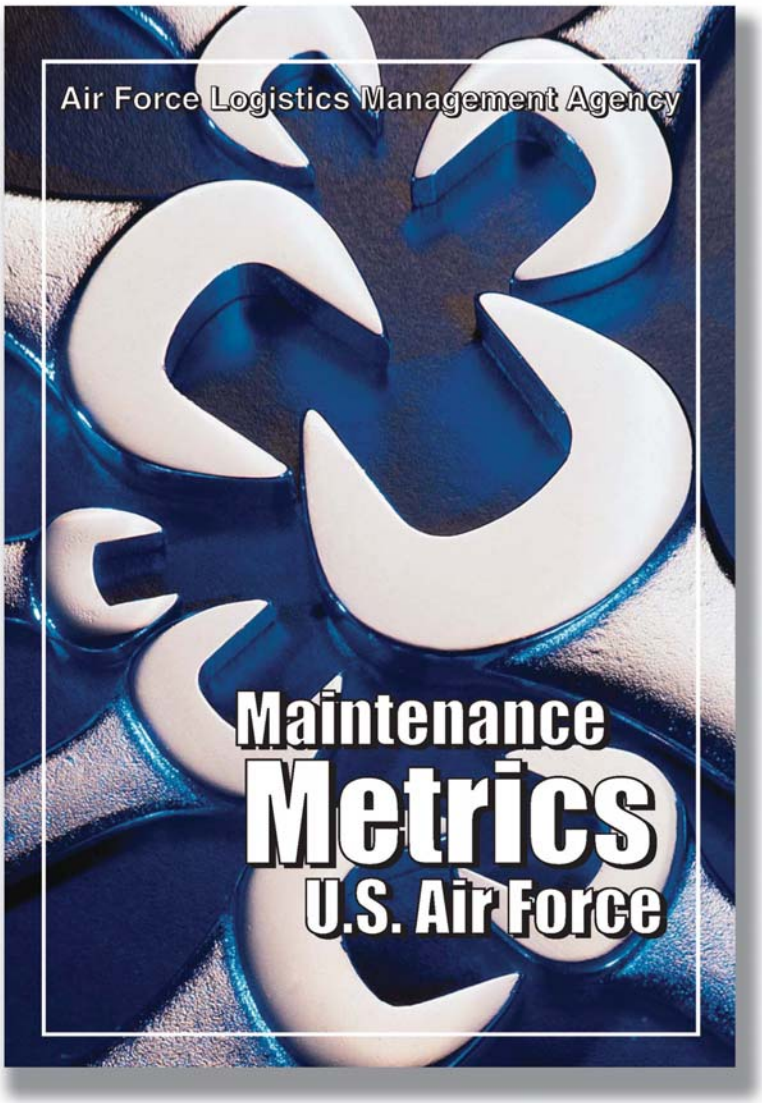

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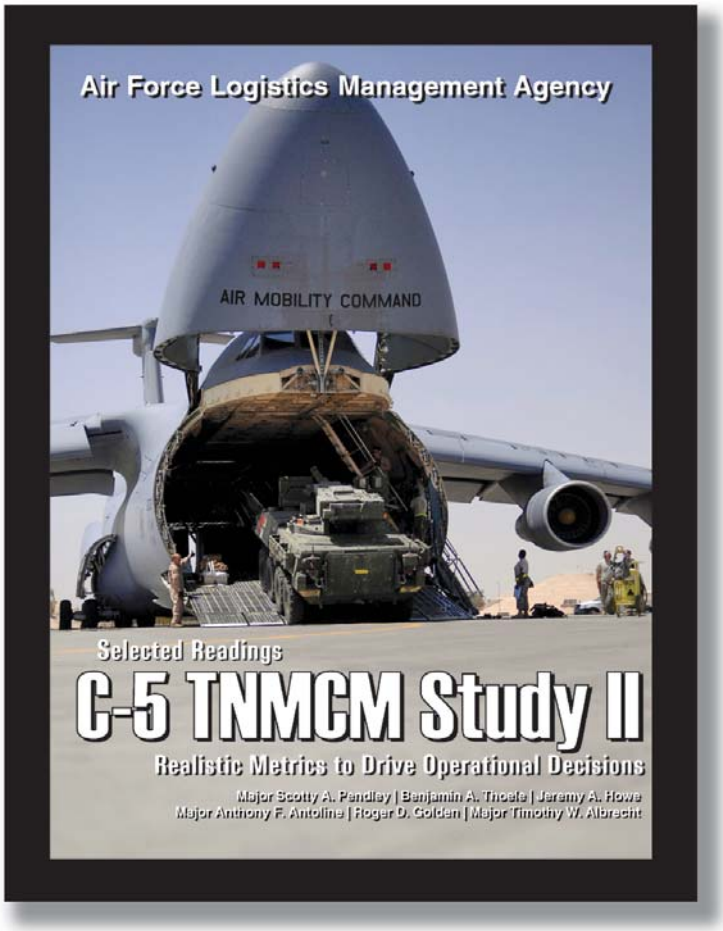

The *C-5 TNMCM Study II* proved to be a stern test of AFLMA's abilities and perseverance. Considering the numerous potential factors that impact TNMCM rates as well as the C-5's historical challenges in the areas of availability and achieving established performance standards, the study team was determined to apply new thinking to an old problem. The research addressed areas of concern including maintaining a historically challenged aircraft, fleet restructuring, shrinking resources, and the need for accurate and useful metrics to drive desired enterprise results. The team applied fresh perspectives, ideas and transformational thinking. As a result, the study team developed a new detailed methodology to attack similar research problems, formulated a new personnel capacity equation that goes beyond the traditional authorized versus assigned method, and analyzed the overall process of setting maintenance metric standards. AFLMA also formed a strategic partnership with the Office of Aerospace Studies at Kirtland AFB in order to accomplish an analysis of the return on investment of previous C-5 modifications and improvement initiatives. A series of articles was produced that describes various portions of the research and accompanying results. Those articles are consolidated in this book.

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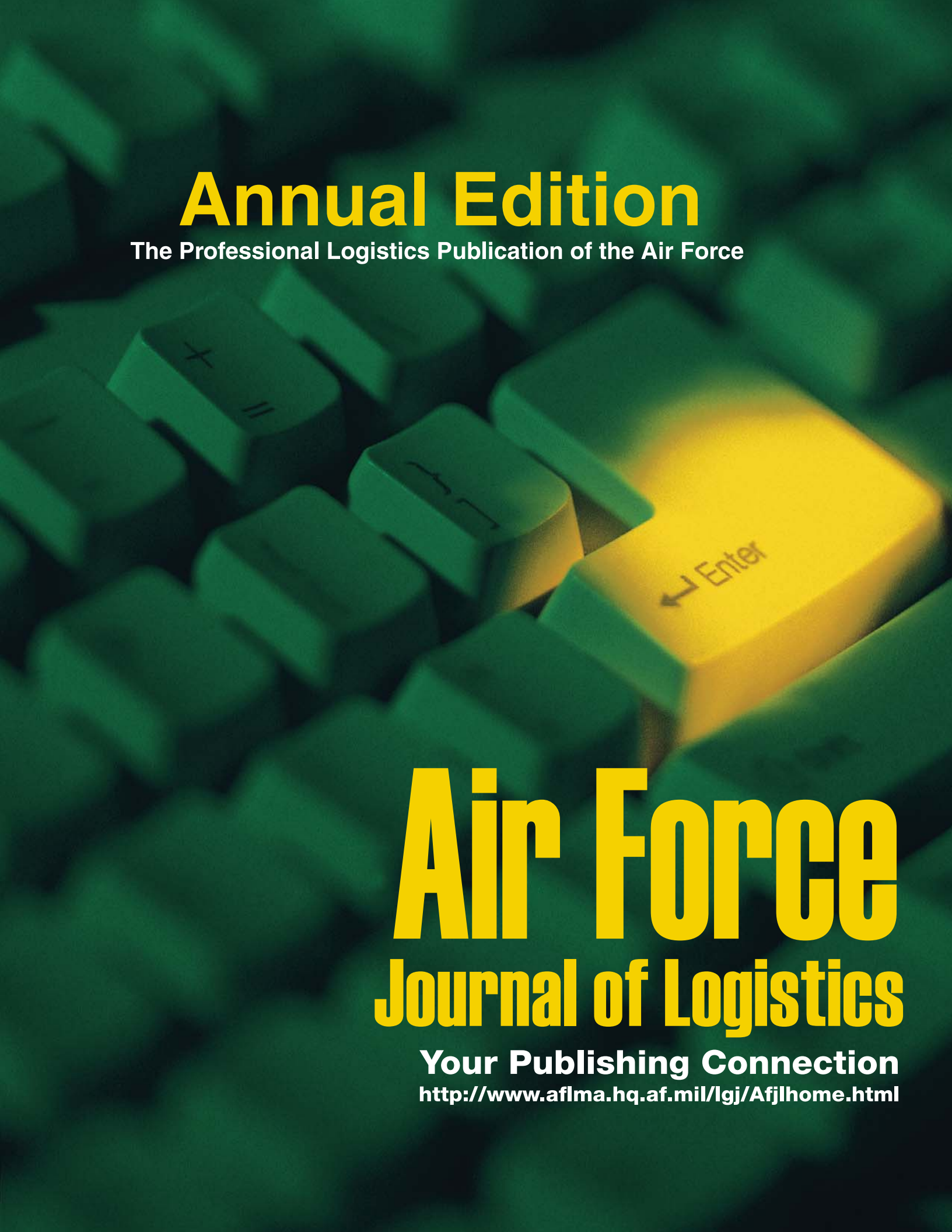

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Cindy Young
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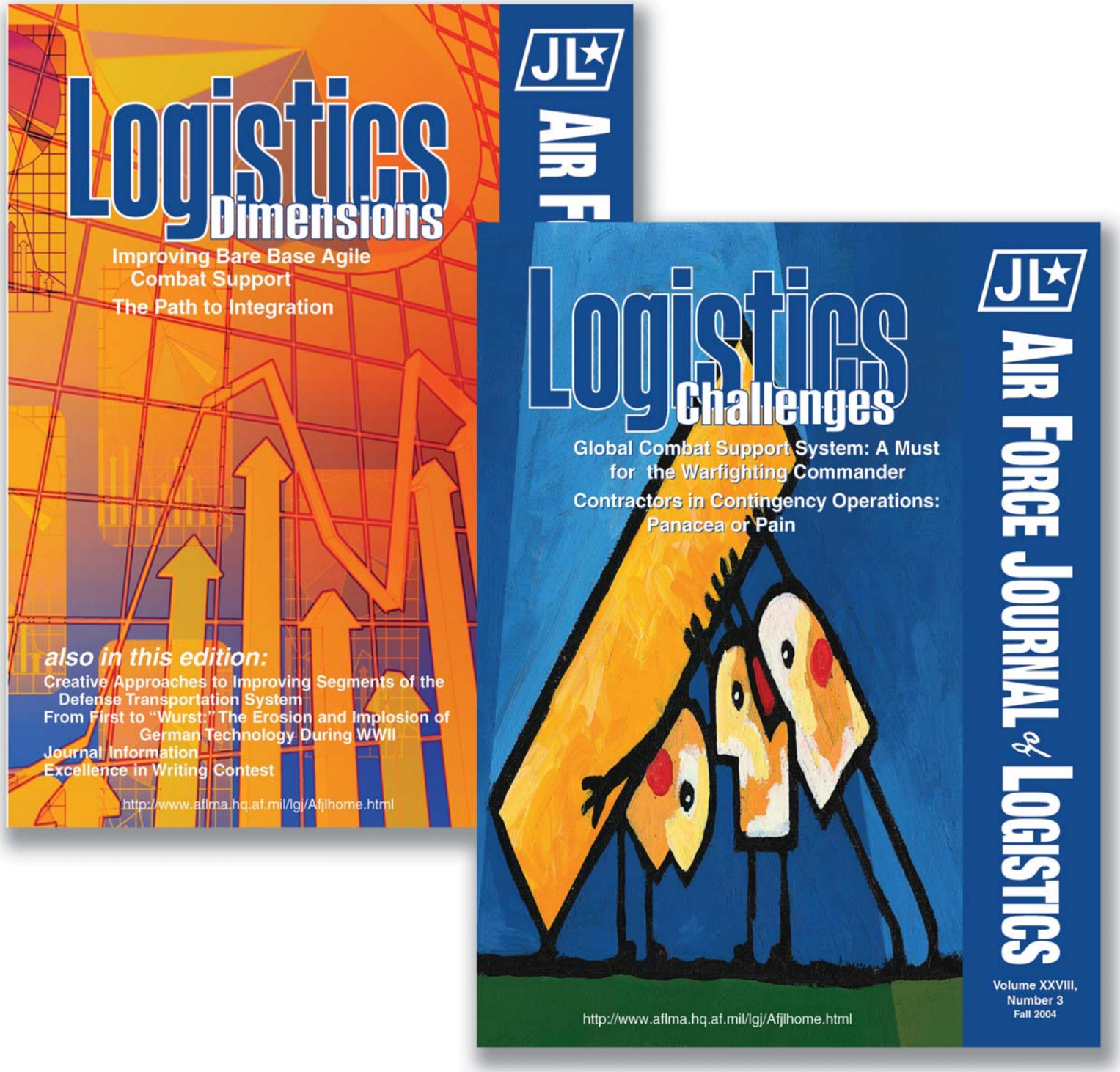

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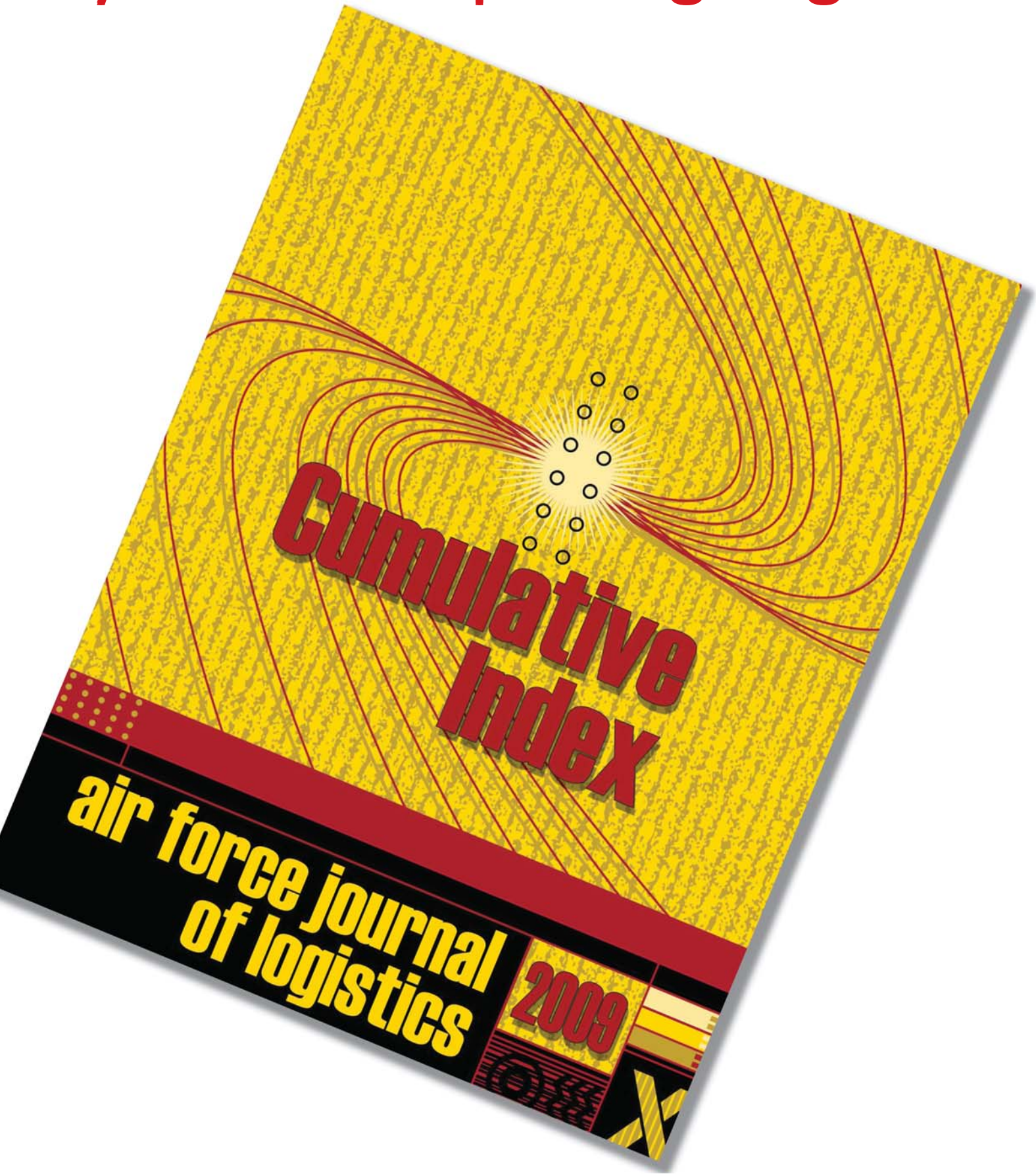

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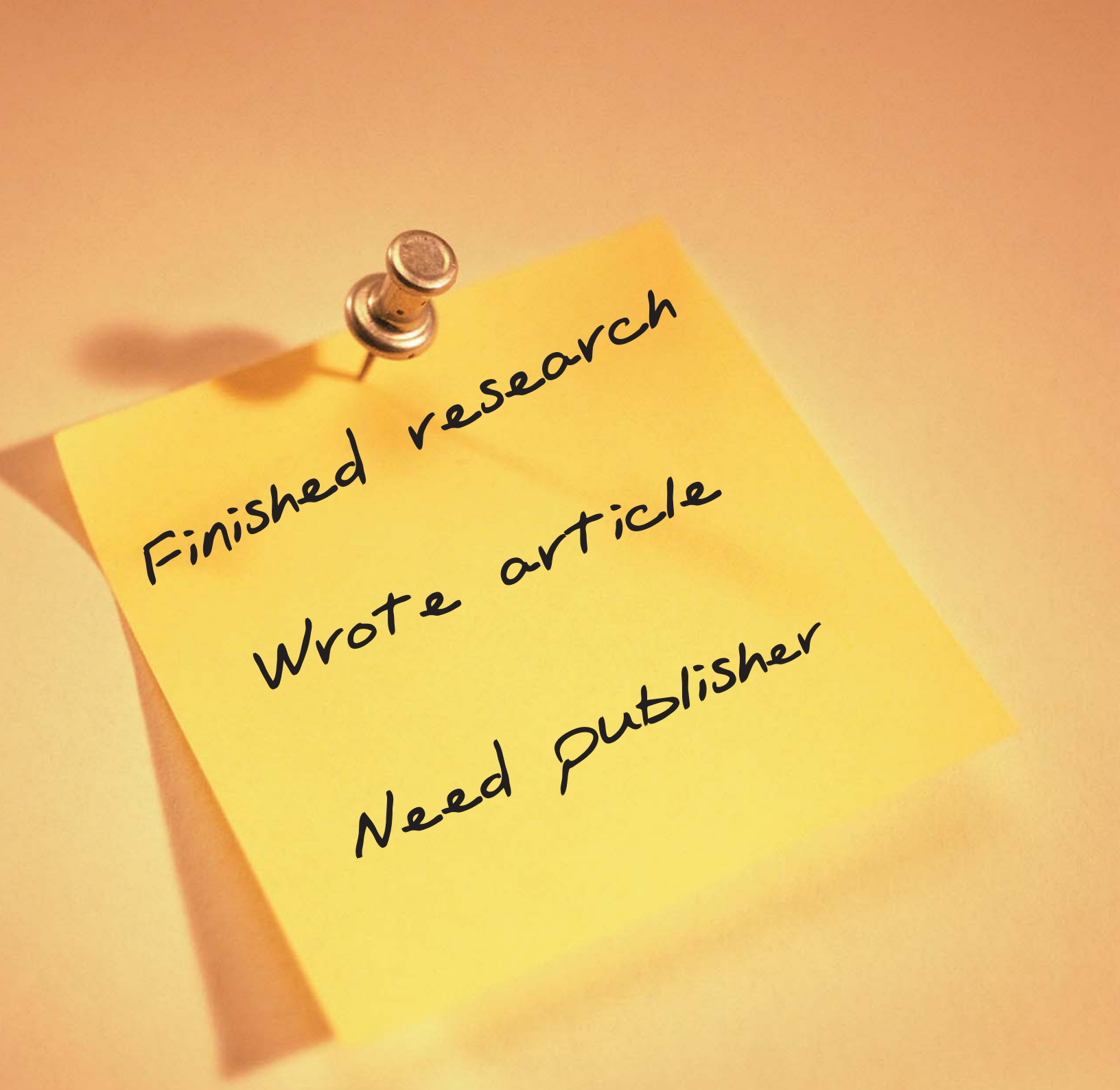
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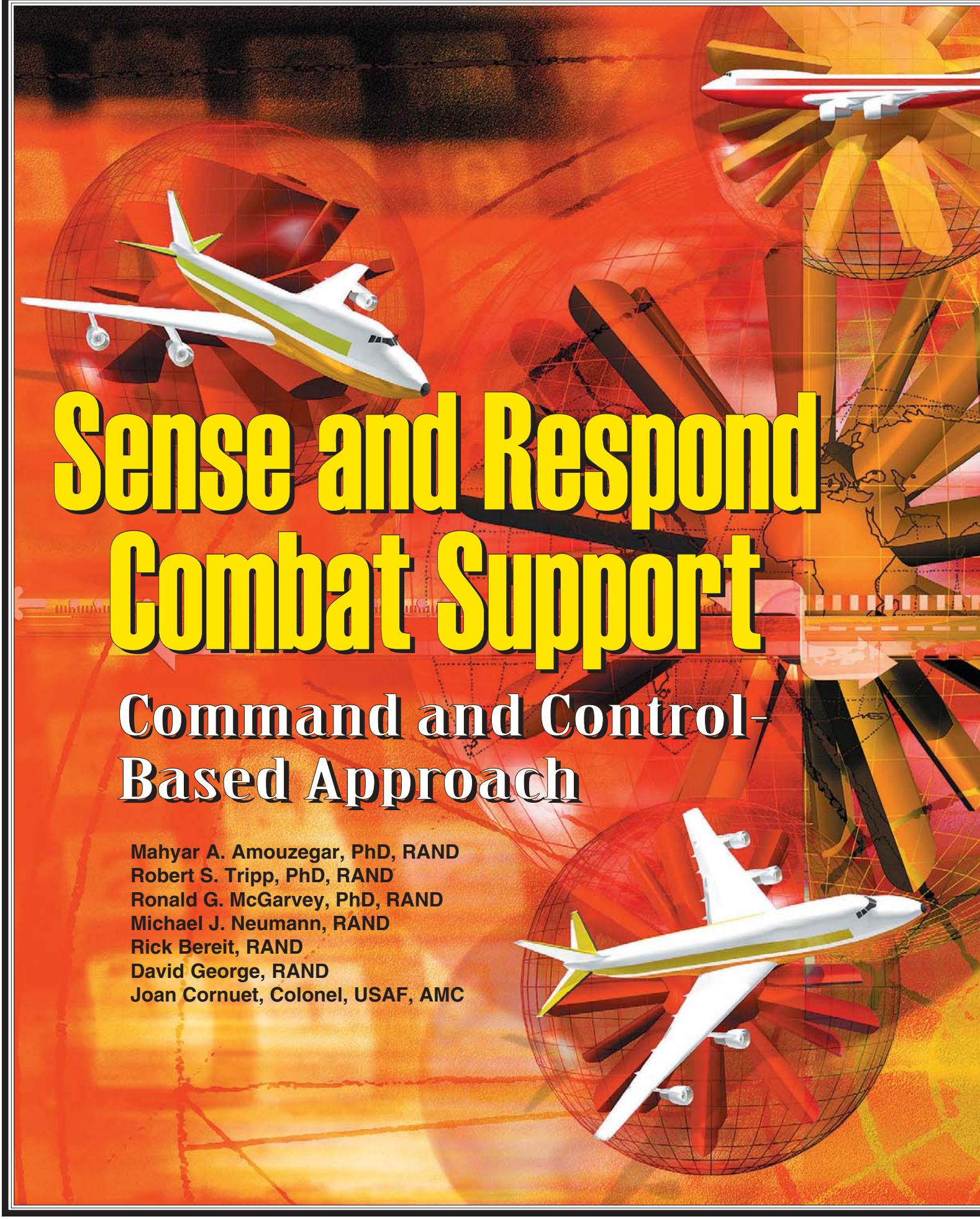

Sense and Respond Combat Support

Command and Control-Based Approach

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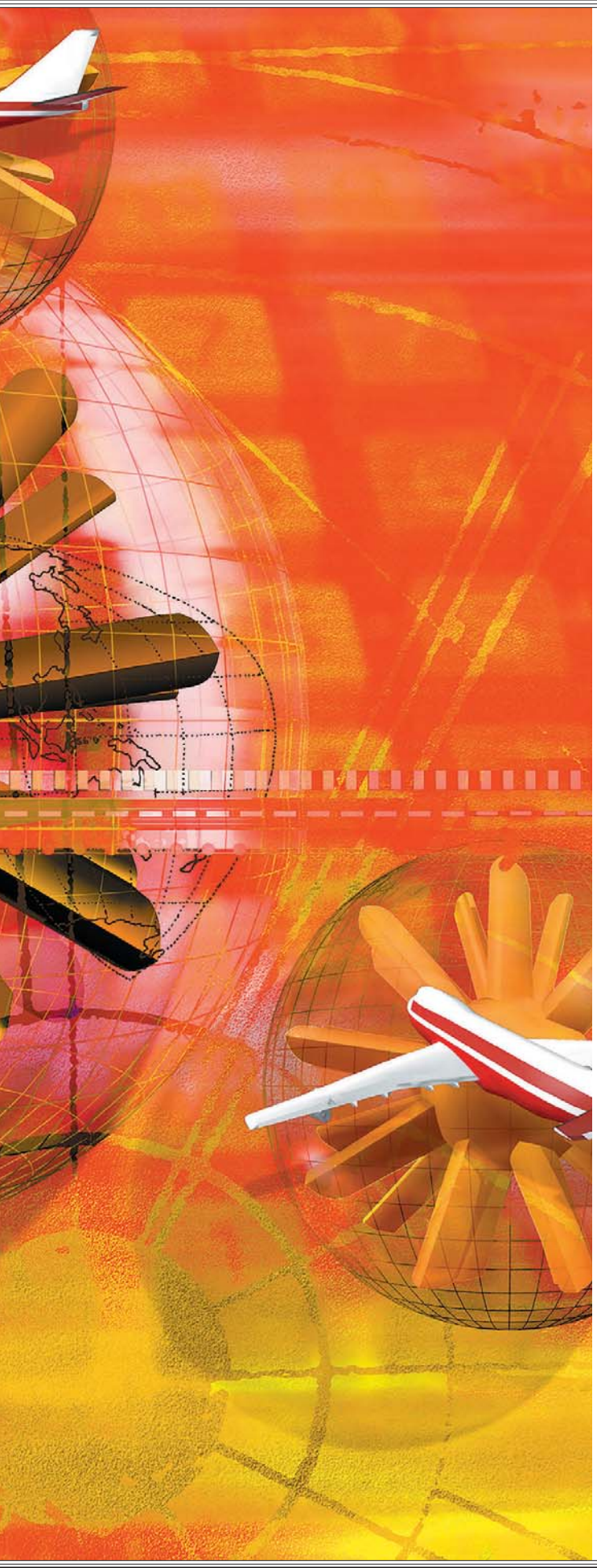

Nothing is too wonderful to be true.

—Kay Redfield Jamison

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 two 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 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.

Article Highlights

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.

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 needed for matching CS assets to warfighter needs. In the past, prediction and responsiveness have been viewed as competing concepts. In "Sense and Respond Combat Support: Command and Control-Based Approach," the authors argue that both are necessary and can be integrated within a command and control system to create military sense and respond capabilities. In the course of the article they outline how this may be accomplished.

The authors conclude by noting that significant challenges remain before the Air Force can realize a sense and respond combat support (S&RCS) capability. To develop effective tools that accurately link logistics levels and rates to

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.

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 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

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.

Article Highlights

operational effects, the modern Expeditionary Combat Support System must be developed and tested in conjunction with operations and intelligence systems.

Technologies associated with S&RL are still in an early stage of development and may not be fielded for a number of years. Ultimately, the Expeditionary Combat Support System should relate how combat support 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 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 Global Logistics Support Center should be in a position to advocate for future improvements while exploring ways to provide the capability utilizing current systems.

Article Acronyms

ABM – Agent-Based Models
ACS – Agile Combat Support
AEF – Air and Space Expeditionary Force
C2 – Command and Control
CoAX – Coalition Agent Experiment
CS – Combat Support
CSC2 – Combat Support Command and Control
DARPA – Defense Advanced Research Projects Agency
DoD – Department of Defense
ECSS – Expeditionary Combat Support System
IT – Information Technology
OFT – Office of Force Transformation
RFID – Radio Frequency Identification
S&R – Sense and Respond
S&RCS – Sense and Respond Combat Support
S&RL – Sense and Respond Logistics

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.

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 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

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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.

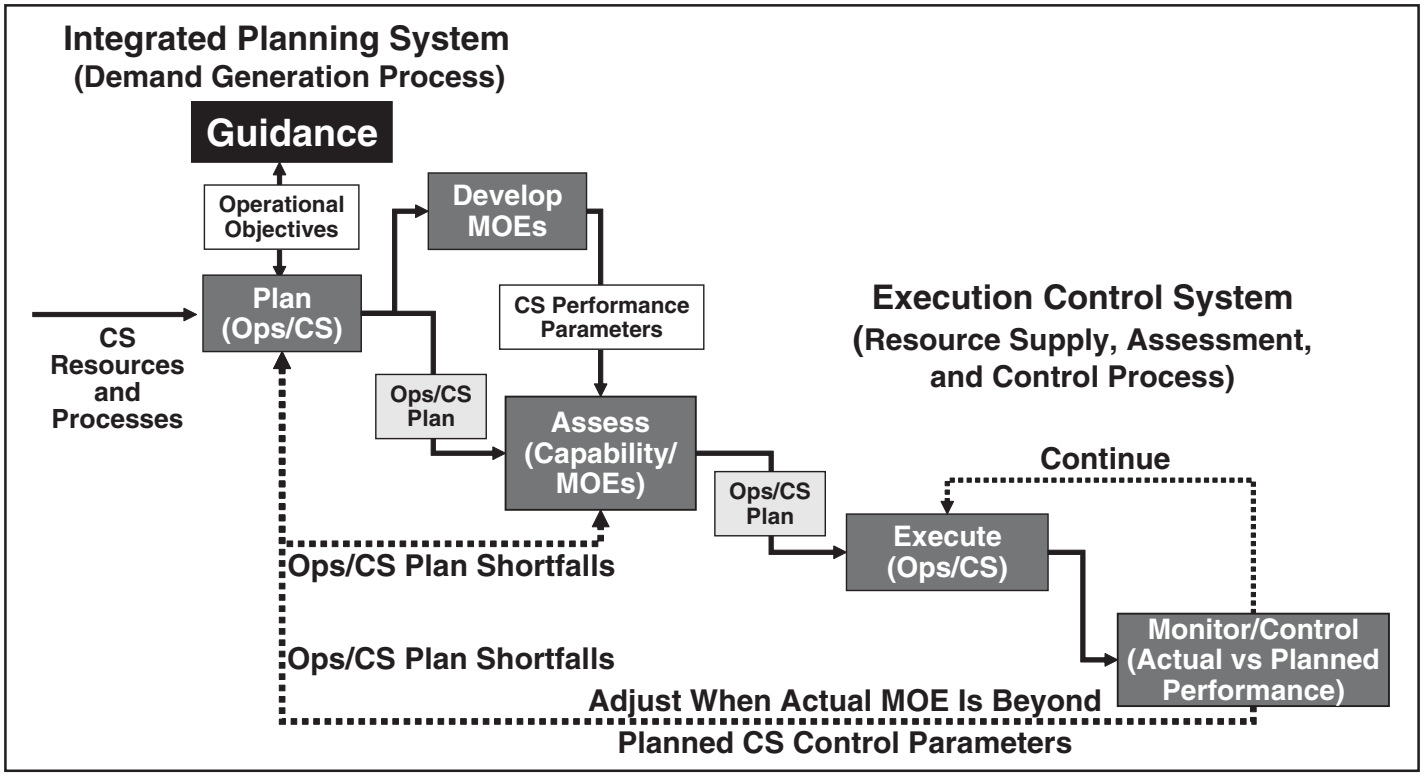

Figure 1. Feedback Loop Process

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 technologies are fairly mature and have been fielded in both commercial and military arenas. 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.

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 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.

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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, time liness, and accuracy of CS planning.

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 support 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:

- 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

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.

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.

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.

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 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.

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.

- **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.
- **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.

End Notes

1. Thomas X. Hammes, "Insurgency: Modern Warfare Evolves in a Fourth Generation," *Strategic Forum, No 214* January, 2005.
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*, March 23, 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.

   Robert S. Tripp, Lionel A. Galway, Timothy L. Ramey, Mahyar A. Amouzegar, and Eric Peltz, *Supporting Expeditionary Aerospace Forces: A Concept for Evolving to the Agile Combat Support/Mobility System of the Future*, Santa Monica, CA: RAND Corporation, MR-1179-AF, 2000.

   Lionel A. Galway, Robert S. Tripp, Timothy L. Ramey, and John G. Drew, *Supporting Expeditionary Aerospace Forces: New Agile Combat Support Postures*, Santa Monica, CA: RAND Corporation, MR-1075-AF, 2000.

   Eric Peltz, Hyman L. Shulman, Robert S. Tripp, Timothy L. Ramey, Randy King, and John G. Drew, *Supporting Expeditionary Aerospace Forces: An Analysis of F-15 Avionics Options*, Santa Monica, CA: RAND Corporation, MR-1174-AF, 2000.

   Mahyar A. Amouzegar, Lionel A. Galway, and Amanda Geller, *Supporting Expeditionary Aerospace Forces: Alternatives for Jet Engine Intermediate Maintenance,* Santa Monica, CA: RAND Corporation, MR-1431-AF, 2002.

   Mahyar A. Amouzegar, Lionel A. Galway, and Robert S. Tripp, "Integrated Logistics Planning for Expeditionary Aerospace Force," *Journal of Operational Research,* Vol 55, 2004.

   Mahyar A. Amouzegar, Robert S. Tripp, Ronald G. McGarvey, Edward Wei-Min Chan, and Charles Robert Roll, Jr., *Supporting Air and Space Expeditionary Forces: Analysis of Combat Support Basing Options*, Santa Monica, CA: RAND Corporation, MG-261-AF, 2004.

   Mahyar A. Amouzegar, Ronald G. McGarvey, Robert S. Tripp, Louis Luangkesorn, Thomas Lang, C. Robert Roll, Jr., *Evaluation Of Options For Overseas Combat Support Basing*, Santa Monica, CA: RAND Corporation, MG-421-AF, 2006.

   James C. Rainey, Mahyar A. Amouzegar, Beth F. Scott, Robert S. Tripp, Ann M. C. Gayer, eds., *Combat Support: Shaping Air Force Logistics for the 21st Century*, Montgomery, AL: Air Force Logistics Management Agency Publisher, August 2003.
6. Air Force Doctrine Document 1, *Air Force Basic Doctrine,* September, 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.
12. US Department of Defense, *Sense and Respond Logistics: Co-evolution of and Adaptive Enterprise Capability*, Concept Document (long version), Washington, DC, 2004, a.
13. *Ibid.* In conversations with Office of Force Transformation (OFT) staff, the timeframe for identifying and developing specific technologies for full implementation of all elements of operational S&RL is 2010 to 2015.
14. Grace Lin, Steve Buckley, Heng Cao, Nathan Caswell, Markus Ettl, Shubir Kapoor, Lisa Koenig, Kaan Katircioglu, Anil Nigam, Bala Ramachandran, and Ko-Yang Wang, "The Sense-and-Respond Enterprise: IBM Researchers Develop Integrated SAR System of Global Value Chain Optimization," *OR/MS Today*, April 2002.
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.
18. For a more detailed discussion of agent based modeling see: Andrew Illachinski, *Artificial War: Multiagent-Based Simulation of Combat,* Singapore: World Scientific Publishing, 2004.
19. E. Bonabeau, C. W. Hunt, and P. Gaudiano, "Agent-Based Modeling for Testing and Designing Novel Decentralized Command and Control System Paradigms," presentation at the 8th International Command and Control Research and Technology Symposium, National Defense University, Washington, DC, June 17-19, 2003.
20. A multiagent system is a collection of agents cooperating or competing with each other to fulfill common and individual goals. See P.L. Davidsson, L. Henesey, L. Ramstedt, J. Törnquist, and F. Wernstedt, "Agent-Based Approaches to Transport Logistics," Proceedings of the 3rd International Joint Conference on Autonomous Agents and Multi-Agent Systems, Workshop on Agents in Traffic and Transportation, New York, 2004.
21. R. Lempert, "A New Decision Sciences for Complex Systems," *Proceedings of the National Academy of Sciences,* Vol. 99, S3, 2002.
22. See for example: H.V.D. Parunak, *Agents in Overalls: Experiences and Issues in the Development and Deployment of Industrial Agent-Based Systems*, Ann Arbor, MI: ERIM Center for Electronic Commerce, 1999.
23. John S. Hollywood, Diane Snyder, Kenneth McKay, and John E. Boon, *Out of the Ordinary: Finding Hidden Threats by Analyzing Unusual Behavior*, Santa Monica, CA: RAND Corporation, MG-126-RC, 2004.
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, August 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.

Mahyar A. Amouzegar *is a senior analyst at RAND and the Associate Dean at California State University, Long Beach.*

Robert S. Tripp *is a senior analyst at RAND.*

Ronald G. McGarvey *is an operations researcher at RAND.*

Michael J. Neumann *is a communications analyst at RAND.*

Richard Bereit *is an adjunct senior analyst at RAND.*

David George *is an adjunct senior analyst at RAND.*

Colonel Joan H. Cornuet*, USAF, is the commander, Mobility Air Forces Logistical Support Center, Air Mobility Command.*

Thinking About Logistics

Understanding the elements of military power requires more than a passing knowledge of logistics and how it influences strategy and tactics. *An understanding of logistics comes principally from the study of history and lessons learned.* Unfortunately, despite its importance, little emphasis is placed on the study of history among logisticians. To compound matters, the literature of warfare is replete with triumphs and tragedy, strategy and tactics, and brilliance or blunders; however, far less has been written concerning logistics and the tasks involved in supplying war or military operations.[1]

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 three major wars (and several minor wars or conflicts) since the turn of the century are more directly linked 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 illustrates this point.

> As the machinery of the Allied Coalition began to turn, armchair warriors addicted to action, and even some of the hastily recruited military experts, revealed a certain morbid impatience for the "real war" to begin. But 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.[2]

Unfortunately, the historical tendency of 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. Arguably, logistics of the 21st century will remain, in the words of one irreverent World War II supply officer, "The stuff that if you don't have enough of, the war will not be won as soon as."[43]

Notes

1. John A. Lynn, ed, *Feeding Mars: Logistics in Western Warfare from the Middle Ages to the Present*, San Francisco: Westview Press, 1993, vii.
2. Charles R. Shrader, *U.S. Military Logistics, 1607-1991, A Research Guide*, New York: Greenwood Press, 1992, 3.
3. Julian Thompson, *The Lifeblood of War: Logistics in Armed Conflict*, Oxford: Brassy's, 1991, 3

The Editors, *Air Force Journal of Logistics*

Shaping Logistics—Just-in-Time Logistics

Geostrategic, economic, and technological changes will make support of air operations, both at home and overseas, increasingly dependent on the flexibility and responsiveness of the military logistic organization. This requires the creation of a highly integrated and agile support chain with global reach. The most promising strategy to achieve these aims is based on a joint management approach, teaming the public and private sectors, under long-term partnering arrangements. While it is probable that organic military maintenance capabilities will be retained, particularly to address life-extension and fleet-upgrade requirements, the alliance partners will largely determine the size and shape of the military logistic organization as part of their wider responsibilities for shaping the overall support chain. Success will be measured by a reduction in inventories, faster turn-round times, more rapid modification embodiment, swifter deployment of new technologies, a smaller expeditionary footprint, lower support costs, and greater operational output.

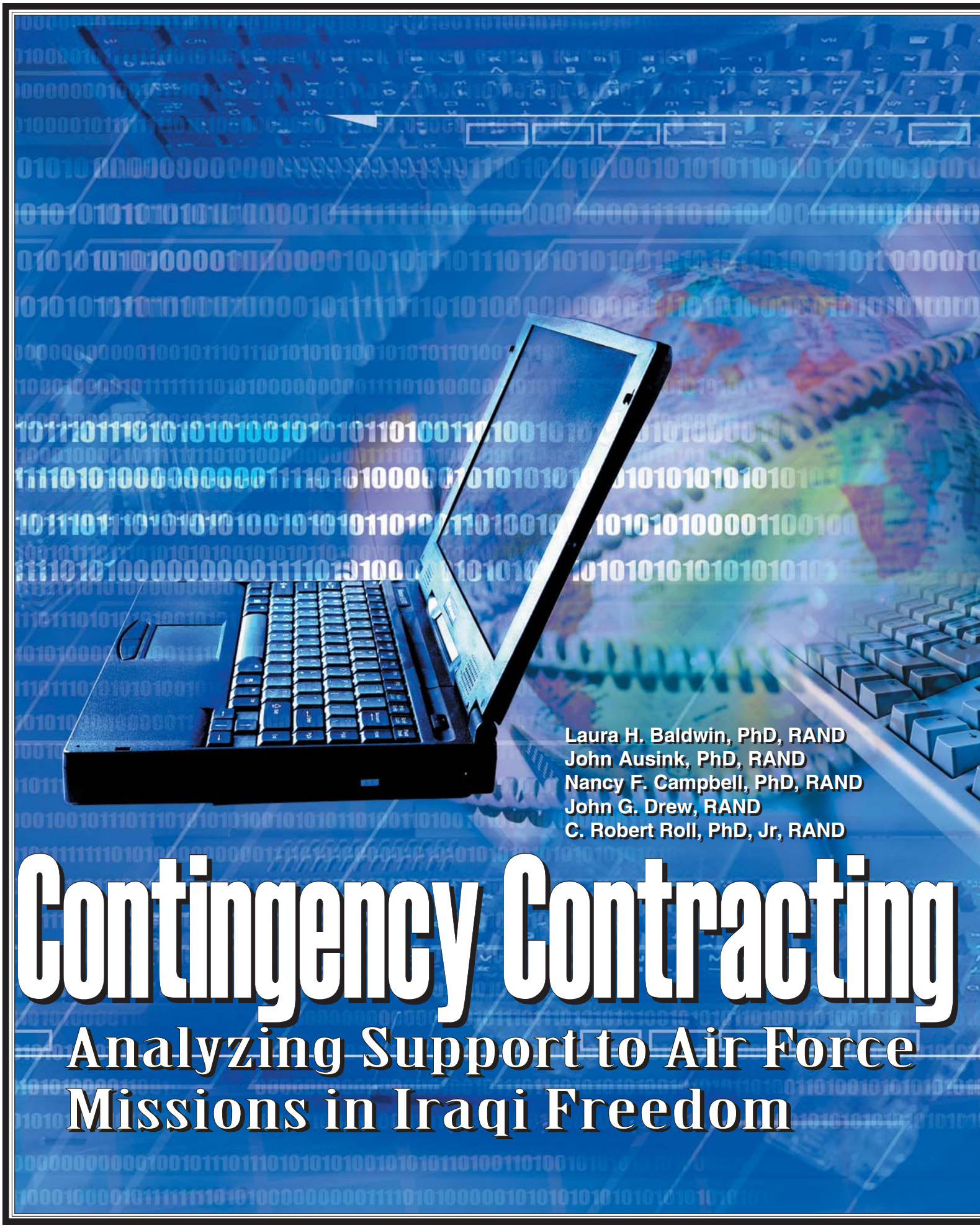
This strategy requires more, however, than the application of just-in-time principles. It embraces commercial express transportation; innovative contracting arrangements including spares-inclusive packages; the application of commercial information technology solutions to support materiel planning and inventory management; collective decisionmaking involving all stake-holders; an overriding emphasis on operational output; and most important, a high level of trust between all the parties. These changes may well result in smaller organic military repair facilities and the greater use of contractors at all maintenance levels, including overseas. Most important, it will require the military aviation maintenance organization to move away from an internal focus on efficiency and utilization to a holistic approach that puts customer needs, in the form of operational output, first and foremost.

As with any new strategy, there are risks. The fundamental building block in determining a successful partnership with industry is *trust*. As one commentator has observed, "Trust is the currency that makes the supply chain work. If it's not there, the supply chain falls apart."[1] As support chains are more closely integrated and maintenance strategies are better aligned, the more vulnerable is the logistic organization to the impact of inappropriate behavior. In the past, the risk might have been minimized and resilience enhanced by providing duplicate or alternative in-house capabilities backed up by large inventories. This is neither affordable nor compatible with today's operational needs. In the future, therefore, the main safeguard will be the creation of an environment in which government and industry, both primes and subcontractors, can function coherently, effectively, and harmoniously.

Notes

1. *Aviation Week & Space Technology*, 13 Sep 99, 75-82.

Group Captain Peter J. Dye, RAF



Laura H. Baldwin, PhD, RAND
John Ausink, PhD, RAND
Nancy F. Campbell, PhD, RAND
John G. Drew, RAND
C. Robert Roll, PhD, Jr, RAND

Contingency Contracting

Analyzing Support to Air Force Missions in Iraqi Freedom

Introduction[1]

Contractors have been an important part of US war efforts since they were hired to take care of cavalry horses for the Continental Army during the Revolutionary War. While the history of contracted support to US military operations is a long one, the role of that support has expanded rapidly and extensively, particularly since the end of the Cold War.[2,3,4] Today the US Air Force, as well as the other US military services, buys an enormous amount and variety of goods and services to support its contingency operations. These purchases are necessary for a wide range of activities, including feeding, housing, and protecting military personnel; repairing aircraft weapon systems; and transporting personnel and supplies. The outcomes of these purchases directly affect the Air Force's ability to succeed in a contingency environment.

Purchasing goods and services to support contingency operations can provide several types of benefits to the Air Force. As with most types of outsourcing, contract support frees up airmen to perform core military activities. Providers that specialize in the outsourced goods or services often can offer improved performance and cost outcomes, if managed effectively. Buying in-theater reduces requirements for scarce transportation resources, potentially shortening deployment time lines, and also garners host-nation support for US military presence. Additionally, having the capability to purchase as needed, rather than being forced to predict requirements in advance, helps commanders meet emerging demands and the often-changing requirements associated with the realities of war.

Since September 11, 2001, the Air Force has been involved in two significant contingency operations in the United States Central Command (USCENTCOM) area of responsibility (AOR): Operation Enduring Freedom (OEF) in Afghanistan, and Operation Iraqi Freedom (OIF) in Iraq. To take advantage of the depth of contingency contracting experience built during recent operations, the Deputy Assistant Secretary of the Air Force for Contracting asked RAND Project Air Force to gather and analyze data on goods and services purchased to support Air Force missions in OIF to determine the size and extent of contractor support for OIF and how plans for and the organization and execution of contingency contracting activities might be improved to better support the warfighter in future operations.

The motivation for this study was that insights from comprehensive data on recent multiyear contingency contracting experiences would help inform decisions about a number of important policy issues.

First, such data could be used to improve the Air Force's ability to plan for combat operations at contingency operating locations, particularly by linking purchases to supplemental information about the phases of operations (such as deployment, the building of a base, the sustainment of operations at a base, or the closing of a base) and mission activities supported by those purchases.

Article Highlights

While price information can be a powerful tool for contingency contracting officers (CCO), additional information about the relative performance of suppliers and other factors related to meeting requirements, such as the urgency, transportation needs, or security threats, would be helpful in interpreting such comparisons.

In "Contingency Contracting: Analyzing Support to Air Force Missions in Iraqi Freedom" the authors describe the construction of a database of CCO purchases supporting Air Force activities in Operation Iraqi Freedom during fiscal years 2003 and 2004. The results of their analysis demonstrate how this database can be a powerful analytic tool to inform and support policy decisions and initiatives for CCO staffing and training, combat support planning, and sharing lessons within the theater.

They recommend the Air Force (and the Department of Defense more broadly) establish a standardized methodology for collecting contingency contracting data on an ongoing basis to facilitate planning and policy decisions for future contingencies.

To facilitate the types of analyses required, the Air Force needs to systematically gather contingency contracting data on an ongoing basis. To be most useful, the CCO data system must make it possible to quickly access detailed

For example, the Air Force could make more informed trade-offs between purchasing required assets as needed during operations in-theater or purchasing them in advance and then using airlift or other transportation assets to move materials from the United States or regional storage locations to operating locations.

Second, purchasing data could be used to improve training for future contingency contracting officers (CCOs). Insights about how purchasing evolves with operational phases could be used to design more realistic training courses. Further, information about typical goods and services purchased, types of contracts used, and supply bases at specific locations could be used to better prepare CCOs before deployment.

Third, information about contracting workloads at different types of bases and other purchasing organizations during different phases of operations could be used to better align CCO organizations and personnel assignments (both CCO numbers and skill levels) with warfighter requirements.

Finally, descriptive data on individual transactions are important inputs in efforts to improve purchasing practices across the theater. For example, CCOs could achieve more effective price negotiations based on improved visibility of prices of similar goods or services, as well as identification of potential opportunities to improve the Air Force's leverage with key suppliers through contract consolidation across commodity groups or sites.

Defining Contingency Contracting for Operation Iraqi Freedom

The Air Force Federal Acquisition Regulation Supplement (AFFARS) provides the following relevant definitions:

- A contingency is "an emergency, involving military forces, caused by natural disasters, terrorists, subversives, or required military operations."
- CCOs are people with "delegated contracting authority to enter into, administer, and terminate contracts on behalf of the Government in support of contingency…operations."[5]

In this article, we use a broad definition of contingency contracting for OIF that includes war preparations in early fiscal year (FY) 2003, the major combat operations in mid-FY 2003, and postwar activities beginning in the latter part of FY 2003. Although United States Central Command Air Forces (USCENTAF) was the primary major command involved in Air Force operations, many other commands and organizations made purchases in support of this effort. For example, purchases were made to support US Air Forces at European bases, Air Force Special Operations Command forces, and Air Mobility Command operations.

Building the Database

To develop a baseline of Air Force contingency contracting for OIF and obtain insights relevant to the policy issues introduced above, we sought to develop a comprehensive database of Air Force OIF contingency purchases, which were made by a large number of organizations around the world. Our analyses are based on CCO purchases at 24 purchasing organizations located within the USCENTCOM AOR that supported OIF during FY 2003 and

FY 2004. These data include more than 24,000 transactions obligating more than $300M.

We chose these data for several reasons. The current lack of visibility into the details of the forward transactions and the decentralized nature of the CCO purchases suggest that there could be opportunities to improve planning for and execution of these activities, for example, through preplanning for certain types of goods or services, more effective price negotiation, or contract consolidation with key suppliers to the AOR. In addition, the numbers of dollars and individual transactions for USCENTAF are much greater than equivalent data received from other commands and organizations that supported OIF.

In order to create a comprehensive Air Force contingency contracting database for OIF, the RAND team used transaction logs maintained by the office of the USCENTAF comptroller, headquartered at Shaw Air Force Base, South Carolina. These data on CCO purchases were tracked in Microsoft® Excel® spreadsheets, which included similar, but not identical, data fields and spreadsheet formats for contract and government purchase card (GPC) files across purchasing organizations in fiscal years 2003 and 2004.[6] As a result, it was necessary for RAND to develop a detailed process to merge these files into an aggregated master database that would enable our analyses.[7]

The Air Force spreadsheets contained data fields such as a text description of the goods and services purchased, the date the purchase was requested, the price paid, and the supplier. In addition, the RAND team created three new variables for our analyses. First, we created a variable for the purchasing organization (the base or other organization) with which the comptroller associated the transaction. Second, we used the text description for each transaction to categorize the purchase according to one or more types of goods or services. And third, we used several pieces of data from the spreadsheets to create a variable for the type of transaction to identify whether the purchase was made using a GPC or a contract vehicle. Contracts are further broken down into blanket purchase agreements[8] (BPAs) and *other* contracts.

Baseline of Contingency Contracting for Operation Iraqi Freedom

This section provides an overview of the results of our baseline analysis of purchases supporting Air Force OIF activities during FY 2003 and FY 2004 at Air Force operating locations in the USCENTCOM AOR. RAND's database allowed the team to analyze the USCENTAF CCO purchases in several important ways. After an overview of expenditures, we describe:

- Who (which organizations) made purchases
- What types of goods and services were purchased
- When the purchases were made (time periods)
- How the purchases were made (contracting tools used)
- From whom (suppliers) the purchases were made

Who

Figure 1 provides information on the time frames for purchasing activity for each of the OIF purchasing organizations during FY 2003 and FY 2004. (Purchasing activity corresponds to operations for each of these organizations.) Only five organizations had contracting activity throughout both years. Some were active for only a few months.

Article Highlights

descriptions of individual transactions, as well as aggregate those transactions according to categories of purchases, types of contract vehicles used, locations of purchases, suppliers dealt with, and so forth.

The authors also recommend establishing a standardized automated system for transaction-specific data that could be either virtually connected to a master database or regularly downloaded into such a database as a means of recording and cataloging purchases. Such a system should also include an easy method both for categorizing purchases across a wide range of commodities and services and for identifying suppliers in a standardized way. Contingency contracting representatives and logistics planners should work in concert to develop the database, ensuring that one standardized system will satisfy the requirements of both organizations.

Article Acronyms

AFFARS – Air Force Federal Acquisition Regulation Supplement
AOR – Area of Responsibility
BPA – Blanket Purchase Agreement
CAOC – Combined Air Operations Center
CCO – Contingency Contracting Officer
USCENTAF – United States Central Command Air Forces
USCENTCOM – United States Central Command
DFAS – Defense Finance and Accounting Service
FY – Fiscal Year
GPC – Government Purchase Card
OEF – Operation Enduring Freedom
OIF – Operation Iraqi Freedom
PSAB – Prince Sultan Air Base
RED HORSE – Rapid Engineer Deployable Heavy Operational Repair Squadron Engineers

An analysis of spending by location indicates that the most spending by far occurred at Al Udeid. Two things may explain this: First, expenditures there include not only those for air base operations, but also for the Combined Air Operations Center (CAOC), which relocated from Prince Sultan Air Base (labeled *PSAB)* to Al Udeid during this period. Second, Al Udeid served as the forward headquarters of the Air Force in Southwest Asia during both OIF and OEF. Unfortunately, Al Udeid's and the CAOC's contract expenditures were captured only in a separate financial management system which lacks the necessary resolution to allow detailed analysis.[9]

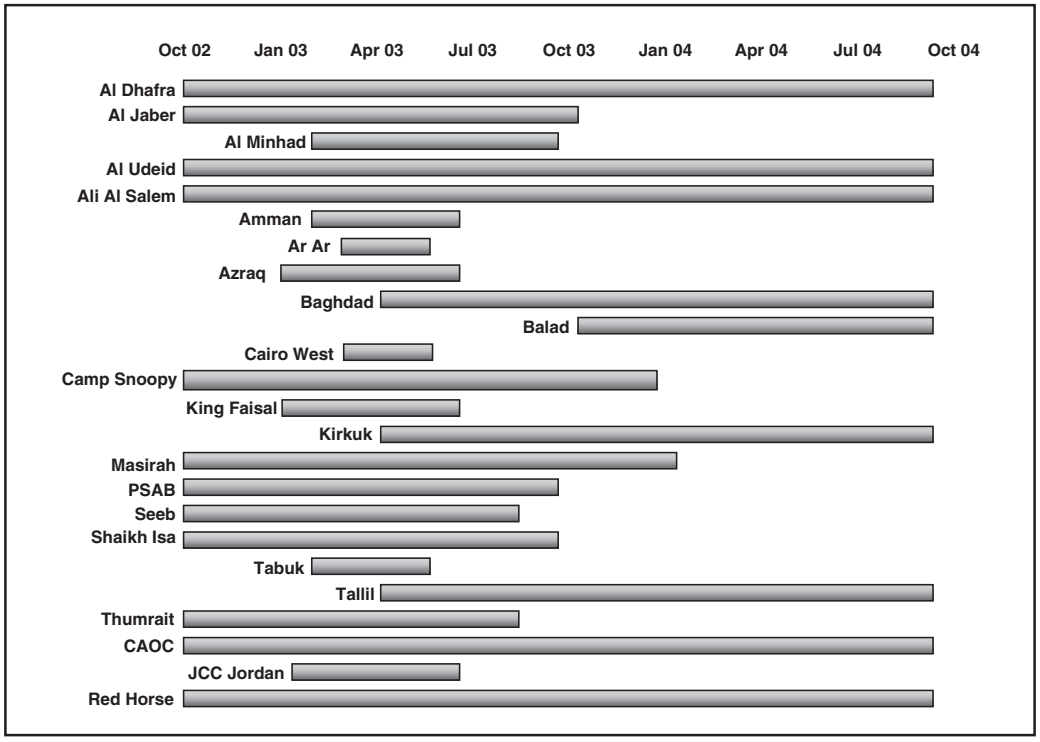


Figure 1. Time Lines for Purchasing Activity, by Purchasing Organization

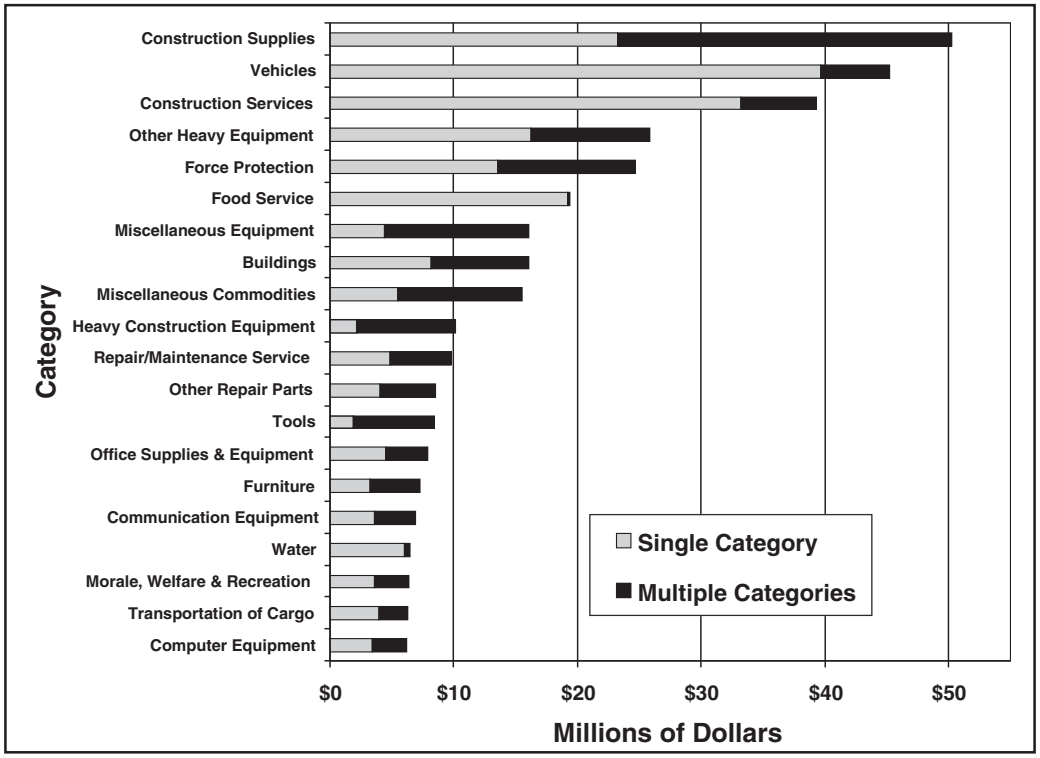


Figure 2. Obligations for the Top 20 Categories, FY03 and FY04

Note: the *single category* portion of the horizontal bars shows obligations that clearly belonged in only one category; the *multiple categories* portion shows obligations for transactions that could also be assigned to other categories.

What

Deployed CCOs purchased a variety of products to support OIF operations during FY 2003 and FY 2004. We created 45 categories of goods and services and used a computer program to assign transactions to these categories based on key words found in the text descriptions of the purchases. After categorizing the transactions as well as possible, we calculated both the total obligations per category as well as the number of transactions per category. The categories with the highest total obligations included construction supplies, vehicles, construction services, and other heavy equipment (see Figure 2).[10] Construction supplies, miscellaneous commodities, and office supplies and equipment represent the largest number of transactions.

When

Our database also allows analysis of purchases over time. Figure 3 shows that CCO purchases and transactions at these purchasing organizations were higher in FY 2003 than in FY 2004. This could be associated with the decline in the number of active bases or any number of other factors.

We can disaggregate these data to examine how the level of expenditures varied over time at individual bases. Such data can be used to make comparisons across locations according to characteristics such as base population, types of operational missions (for example, special operations, F-16s), existing base infrastructure, or permanency of the operating location.

While our database alone cannot address underlying causes for the observed differences in spending patterns across locations

over time, an analyst with additional information about characteristics of locations such as base population, numbers and types of aircraft, types of missions, types and maturity of base infrastructure, geographic dispersion of facilities, and Service branch responsible for base operating support, could perform more sophisticated evaluations to determine the correlation between these factors and spending patterns over time.[11] The results of such analyses could be used to make programming decisions about new bases, plan transportation requirements, match CCO resources with user requirements, and so forth.

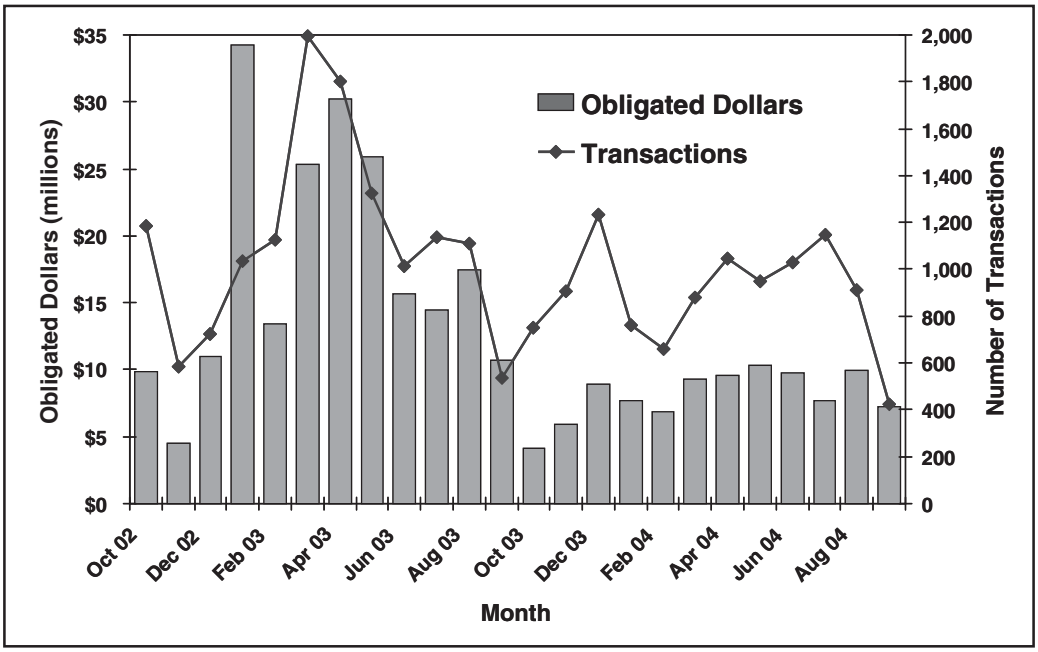


Figure 3. Obligations and Transactions by Month, FY03 and FY04.

How

CCOs have a variety of instruments with which to make purchase payments. Our data allow us to identify two particular types of instruments for further analysis: GPCs (essentially government-issued credit cards) and BPAs. Here, we compare purchases made using GPCs to purchases made through contract instruments that are recorded in USCENTAF comptroller files. As shown in Figure 4, GPC purchases represented more than one-third of the transactions made in fiscal years 2003 and 2004 , but they represented less than one-tenth of the dollars spent.

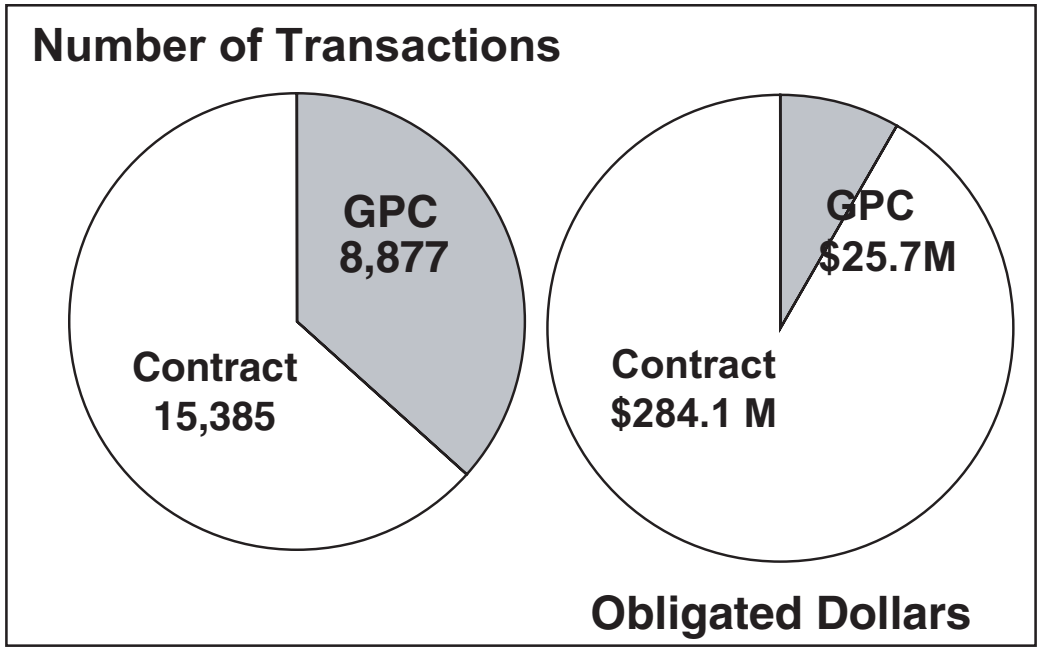


Figure 4. GPC versus Contract Purchases in FY03 and FY04.

Since GPCs are designed for purchases of small items, such as office supplies—many of which can be made over the Internet—this is an understandable finding. The dollar amount for the average contract transaction was about 6 times larger than the amount for the average GPC transaction.

Although GPCs are intended for the purchase of small items, it is interesting to note that construction supplies are the largest category for both GPC and contract transactions. Other contract transactions were concentrated in construction services and larger goods, including vehicles and heavy equipment, while GPC purchases included smaller equipment, tools, and office supplies.

From Whom

Having examined who made what purchases, and when and how the purchases were made, we now turn to the question of from whom goods and services were purchased. We examined the top 10 suppliers (in terms of dollars obligated) in fiscal years 2003 and 2004 by all obligations, for contract obligations alone, and for GPC obligations alone.[12]

Based on firm names, the top firms by contract expenditures appear to be regional firms primarily, whereas GPCs were often used to make purchases from US firms, presumably over the Internet. To get a better sense of what percentage of Air Force CCO purchases were with regional firms, we examined the top 100 firms used in fiscal years 2003 and 2004, which represented 78 percent of the obligations during this period. Of these, 55 were regional firms. Breaking this out by type of transaction, 59 of the top 100 firms for contract transactions were regional, while the number was much smaller for GPC purchases, where only 11 out of 100 were regional.

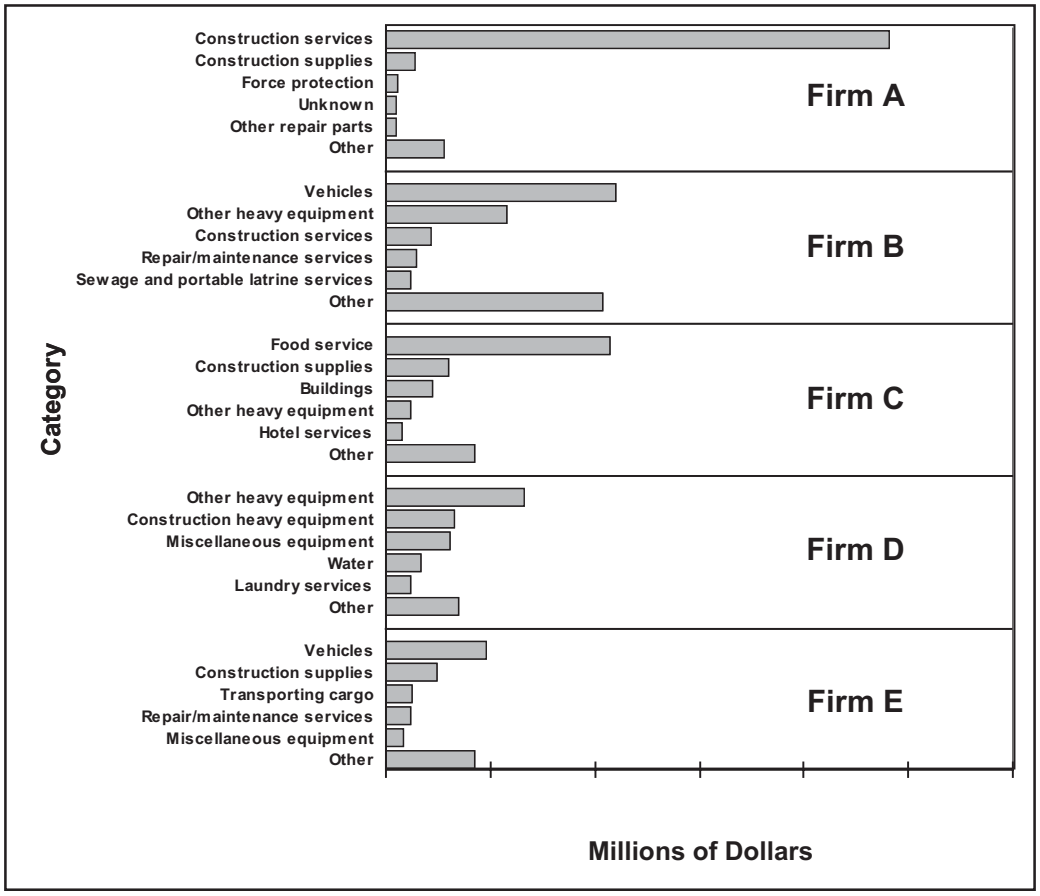


Figure 5. Top Five Purchase Categories for the Top Five Suppliers
Note: one of the top categories of purchases from firm A consisted of items that our computer program found difficult to categorize and so placed in the *unknown* category.

The top-ranked suppliers provided goods and services from a variety of categories. For each of the top five suppliers in fiscal years 2003 and 2004 (noted as Firms A through E), Figure 5 displays the top five categories of purchases made through the supplier (with all other purchases counted in the bar labeled *Other*).

Top suppliers worked across multiple locations as well. In particular, Firm E supplied goods and services not only in Iraq, but also in Qatar and Oman.

Such detailed information on suppliers' activities across the theater can assist CCOs in planning future acquisitions. While no contracts in our database encompassed more than one purchasing organization, there may be opportunities for the Air Force or the Department of Defense to increase leverage with providers by combining contracts across organizations and encouraging competition among providers. RAND's data analyses of suppliers point to more detailed analyses that could inform such strategic purchasing decisions.

Implications for Policy Issues

In this section, we use insights from the data and from interviews we conducted in the course of our research to address issues related to CCO staffing, CCO training, combat support planning, and the sharing of lessons within the theater.

CCO Staffing

Lacking hard data for detailed workload analyses, the Air Force traditionally has used general rules based on perceptions of past experience to determine how many contracting officers to allocate to deployed locations. This approach can lead to the need for adjustments after the fact to reflect real demands on CCOs' time.

One potentially important use of our database could be the systematic assessment of CCO workloads — measured in dollars obligated or transactions executed — across purchasing organizations. While neither measure is perfect (some small-dollar transactions may require more time and attention than do some big-dollar transactions), both measures are potentially important indicators of CCO time requirements. Having received supplemental data from USCENTAF on CCO staffing for selected purchasing organizations for FY 2004, we compared the workload of contracting officers in terms of the average number of transactions per CCO and the average number of dollars obligated per CCO.

Our analyses indicate that there were large differences in CCO activities across locations during fiscal year 2004. However, a better understanding of the nature of activities at individual locations is necessary to draw conclusions. With additional information on the nature of the work within these organizations—such as mission activities supported, types of goods and services purchased, and the number of transactions completed—statistical analyses such as regressions could be used to understand the factors associated with these differences.

CCO Training

Anecdotes from our interviews indicate that a number of factors make contracting in-theater challenging, including differences in the nature of contingency contracting duties as opposed to duties of a contracting officer at a nondeployed location, variation in the contracting environments among countries within the AOR, the short duration of most deployments for contracting personnel,[13] and differences in contracting culture among the military branches operating in a Joint environment.

At first glance, there appears to be abundant guidance available to CCOs to help mitigate any adverse effects associated with these challenges, including AFFARS Appendix CC for Air Force contingency contracting support;[14] Air Force Instruction 10-401, *Air Force Operations Planning and Execution*;[15] the 2003 Air Force Logistics Management Agency contingency contracting handbook;[16] as well as formal training through the Defense Acquisition University[17] and predeployment orientation programs (limited to office chiefs) provided by USCENTAF contracting.

However, one officer we interviewed likened learning CCO procedures from formal training to learning to play golf by reading the rulebook. In contrast, several people mentioned the importance of providing deploying CCOs with opportunities to engage in training simulations (such as Silver Flag exercises[18]) which present them with scenarios they can expect to encounter when they go into the AOR.

A database of CCO purchases such as the one RAND developed (as described above), could supplement classroom and predeployment training by providing insights into ongoing activities in the theater. Information could be tailored to locations where trainees would be deploying. It also could assist in creating more realistic environments for exercises. In addition, a CCO who is getting ready to deploy could use the database to prepare by becoming familiar with the detailed contracting environment at his or her future location, including the types of purchases made, the predominant types of contracts used for these purchases, and the local supply base. Similar data on contracting for other military branches and coalition partners could be used to better prepare CCOs who will be operating in a Joint requirements environment.

Combat Support Planning

Combat support planners are responsible for making sure all of the resources the Air Force needs to go to war are in place in time to support contingency operations and associated personnel. After determining all the necessary resources, planners must make choices about where to obtain them and how to get them to the theater to shorten the deployment-to-employment time line, make the best use of scarce airlift and other transportation resources, and reduce the military footprint in-theater.

Since one option that planners consider is the availability of resources in-theater, a motivation for the development of the OIF CCO database was that such data could be used to improve combat support planners' ability to make effective, efficient trade-offs between purchasing items in-theater and purchasing them elsewhere and then using scarce transportation resources to bring them to the theater. In addition, these data can be used to describe the local supply base for different types of purchases.

The purchase of bottled water in Iraq provides a simple case study of how a detailed database of CCO purchases can be used to help assess the trade-offs among options. The US military required a great deal of bottled water for personnel stationed in locations supporting OIF during fiscal years 2003 and 2004. Our database indicates that CCOs in 15 purchasing organizations in-theater purchased bottled water through 38 contracts with more than 30 suppliers. Alternatively, planners could have elected to set up contract vehicles for large quantities of water in advance (or purchase and store the water) and then ship the water to appropriate locations in-theater as needed. Presumably, such advance planning would result in a lower cost per liter than CCOs were able to negotiate in real time during contingency operations. However, shipments of water into the theater would either delay the transport of troops and other supplies or would require the purchase of additional transportation.[19]

A combat support planner could use RAND's database to determine the best way to meet water requirements in-theater during operations. The database would assist the planner by enabling the assessment of costs associated with purchasing water in-theater, an analysis of the amount of airlift required for an alternate approach, and the identification of any potential effects on the mission.

In addition, data on Joint contracting in-theater, similar to those analyzed in this article, could be used by the combatant commands to construct more realistic and detailed contract support plans. These plans are intended to outline personnel requirements, organizational structures, and so forth, which will be used for Joint contingency contracting to support operations executed by the combatant commands (for example, at what point contracting should transition from a decentralized, service-specific structure to Joint organizations).

Sharing Lessons

The nature of particular requirements and the local environment may limit the CCOs' ability to reduce costs. However, awareness of details of purchases made by other CCOs in the theater should assist in negotiating better prices where this is possible. For example, Table 1 shows the maximum, minimum, and average prices paid per liter of water in fiscal years 2003 and 2004 transactions in our database.

The purchase for Baghdad in Table 1 was for 64 pallets of bottled water, which under our assumptions, equates to 110,592 half-liter bottles, or 55,296 liters. If the Baghdad CCO had been able to obtain this water for the price paid at Al Jaber, he or she would have saved more than $53K. Of course, the majority of the cost for the Baghdad purchase may be attributable to the challenges of delivering into that location.

While price information can be a powerful tool for CCOs, additional information about the relative performance of suppliers and other factors related to meeting requirements, such as the urgency, transportation needs, or security threats, would be helpful in interpreting such comparisons.

Recommendations

In this article, we have described the construction of a database of CCO purchases supporting Air Force activities in OIF during fiscal years 2003 and 2004. We have demonstrated how this database can be a powerful analytic tool to inform and support policy decisions and initiatives for CCO staffing and training, combat support planning, and sharing lessons within the theater.

Based on our experience creating the database and analyzing the CCO data for OIF, we recommend the Air Force (and the Department of Defense more broadly) establish a standardized methodology for collecting contingency contracting data on an ongoing basis to facilitate planning and policy decisions for future contingencies.

To facilitate the types of analyses illustrated here in a timely way, the Air Force needs to systematically gather contingency contracting data on an ongoing basis. To be most useful, the CCO

Category	Maximum	Minimum	Average
Price per liter ($)	1.08	0.12	0.38
Date	March 2004	June 2003	
Location	Baghdad	Al Jaber	

Table 1. Range of Prices CCOs Paid per Liter of Drinking Water, FY03 and FY04

data system must make it possible to quickly access detailed descriptions of individual transactions, as well as aggregate those transactions according to categories of purchases, types of contract vehicles used, locations of purchases, suppliers dealt with, and so forth.

Table 2 contains our recommendations on the types of data that would be most useful to collect. These recommendations encompass data about the transactions themselves, as well as supplemental information about the activities supported by individual purchasing organizations and the relevant supply bases, that would enhance the types of analyses illustrated in this article and provide a basis for interpreting their results.

We understand the complex and austere conditions in which CCOs often operate. Additionally, we do not propose to overburden these hard-working individuals with new reporting requirements. We do suggest a standardized automated system for transaction-specific data that could be either virtually connected to a master database or regularly downloaded into such a database as a means of recording and cataloging purchases.[20] Such a system should also include an easy method both for categorizing purchases across a wide range of commodities and services and for identifying suppliers in a standardized way. For example, drop-down menus with category options and supplier name options from which to choose would make it easier for CCOs to identify these in a consistent manner. Contingency contracting representatives and logistics planners should work in concert to develop the database, ensuring that one standardized system will satisfy the requirements of both organizations.

The Air Force is in the process of reviewing current contracting organizations, including those overseas, to determine what future organizations should look like. In addition, the Air Force is actively engaged in discussions about how to improve the effectiveness and efficiency of contracting in a Joint contingency environment, in which forces from different military branches are collocated and are operating together. The analytic capabilities recommended in this article as well as the corresponding RAND monograph[21] can provide key inputs to these important organizational and operational decisions.

End Notes

1. This article is based on the RAND monograph *Contingency Contracting Purchases for Operation Iraqi Freedom (Unrestricted Version)*, MG-559/1-AF, 2008. We thank our RAND colleague Mike Neumann for his help creating this short article.

TYPE OF DATA	EXPLANATION
Individual Transactions	**Data to be Entered by Purchasing CCO**
Purchasing organization	Organization that purchases the goods or services
CCO	Individual responsible for the transaction
Recipient	Organization or location that benefited from the purchase, if different from the purchasing organization (such as base that benefited from a RED HORSE repair project)
Text description	Description of full range of goods and services purchased through the transaction
Units	Number of goods purchased or period of time for which service is to be provided; break out according to types of goods or services covered within the transaction
Purchase category	General class(es) of goods or services purchased; break out according to types of goods or services covered within the transaction
Price	Price paid for the goods and services; when multiple goods and services are purchased within a single transaction, prices should be broken out by type
Supplier	Firm that provides the goods and services
Location of supplier	Identifies whether supplier is a local firm, regional firm, or other
Transaction ID	Unique identifier for the transaction, such as contract number
Payment mechanism	GPC or contract
Type of contract	For contracts, type of contract, such as BPA, Form SF44
Date of request	Date on which purchasing organization received the formal request for goods and services
Date of payment	Date on which supplier was paid
Date of delivery	Date on which goods were delivered or services began
Comments	Any explanatory comments CCO deems useful
Activities Supported by Purchasing Organizations	**Supplemental Data Needed to Explain Purchasing Trends (will vary over time)**
Population	Number of personnel supported by the purchasing organization
Mission activity	Description of mission activity supported by the purchasing organization's transactions (number and types of aircraft, special operations)
Responsibility for base operating support	Service branch responsible for providing base operating support for the location
Infrastructure	Number of buildings, acres supported by the purchasing organization
Condition of infrastructure	Condition of infrastructure supported by the purchasing organization, particularly for new locations
Outlook	Plans for the purchasing organization (temporary operating location)
Supply base	Supplemental data to facilitate improved purchasing over time
Supplier ratings	Performance ratings of suppliers (perhaps only key suppliers) based on, for example, the quality of goods and services, reliability, and ease of working relationship

Table 2. Recommended Data to Be Collected on an Ongoing Basis

2. George A. Cahlink, "Send in the Contractors," *Air Force Magazine*, Vol 86, No 1, [Online] Available: http://www.afa.org/magazine/jan2003/0103contract.asp, January 2003.
3. Frank Camm and Victoria A. Greenfield, *How Should the Army Use Contractors on the Battlefield? Assessing Comparative Risk in Sourcing Decisions*, Santa Monica, CA: RAND Corporation, MG-296-A, 2005, [Online] Available: http://www.rand.org/pubs/monographs/MG296, as of 7 February 2008.
4. Congressional Budget Office, *Logistics Support for Deployed Military Forces*, Washington, DC, [Online] Available: http://www.cbo.gov/ftpdocs/67xx/doc6794/10-20-MilitaryLogisticsSupport.pdf, October 2005, as of 7 February 2008.
5. *Air Force Federal Acquisition Regulation Supplement*, Appendix CC, paragraph CC-102, 14 March 2007.
6. In most cases, these databases represent all available data on CCO purchases at the identified locations. However, seven of these purchasing organizations recorded some or all of their contract transactions during this period in a centralized electronic database called the BQ system, rather than in the financial management spreadsheets. (The BQ system is the US Air Force's standard base-level general accounting and finance system. Its structure and use are described in DFAS [2000].) Although we were given information about the dollar amount of purchases recorded in BQ, the BQ data do not provide detailed descriptions of these purchases. In addition, we do not know the number of transactions associated with the dollars in the BQ system. Because data for these locations are incomplete, encompassing only GPC expenditures in some cases, we are unable to include them in some of the analyses in this article.
7. As part of the process, we reviewed and corrected several variables, including dates associated with each purchase and information related to contractors.
8. BPA contracts are used to satisfy anticipated recurring requirements for goods or services. They are designed to reduce transaction costs and speed up the procurement process "by establishing *charge accounts* with qualified sources of supply" (Air Force Audit Agency, 2004). The contracts specify the range of goods and services covered by the agreement, price lists, total dollar limits, and time limits. Contracting officers (or other authorized and trained personnel) can then place *calls* against those agreements to meet specific user requirements that fall within the bounds of the agreements.
9. See Footnote 6. In many of the detailed analyses presented in this article, we exclude seven organizations for which we have only partial contracting information; those excluded are Al Dhafra, Al Jaber, Al Udeid, Ali Al Salem, CAOC, Prince Sultan Air Base, and Seeb.
10. In many cases, the description of a purchase clearly fits into only one category. Other transactions included purchases of more than one disparate item or items that were ambiguously described and might, because of the use of key words in the program, fit into more than one category. For example, the text description might include a laptop computer (computer equipment) and a printer (office supplies and equipment), or the purchase may be described as a *desk for chapel* which could be interpreted by the computer program as furniture (the desk) or MWR (the chapel). The *single category* portion of the horizontal bars in Figure 2 shows obligations that clearly belonged in only one category; the *multiple categories* portion shows obligations for transactions that could also be assigned to other categories.
11. Such information would need to be dynamic due to the fluid nature of wartime operations.
12. We cannot list firm names here due to operational security considerations.
13. Typical deployments increased from 3 months to 4 months during our data timeframe, fiscal years 2003 and 2004.
14. *Air Force Federal Acquisition Regulation Supplement*, Appendix CC, paragraph CC-102.
15. AFI 10-401, *Air Force Operations Planning and Execution*, 25 April 2005.
16. James Roloff, *Contingency Contracting: A Handbook for the Air Force CCO*, Maxwell AFB, AL: Air Force Logistics Management Agency, February 2003. [Online] Available: http://www.aflma.hq.af.mil/lgj/contingency%20Contracting%20Mar03_corrections.pdf. In 2007 The AFLMA released new handbook entiled Contingency Contracting: A Joint Handbook.
17. Defense Acquisition University, *2006 Defense Acquisition University Catalog*, Ft Belvoir, VA: DAU Press, October 2005. The course CON 234 (Contingency Contracting) is designed to help develop "skills for contracting support provided to Joint Forces across the full spectrum of military operations" (DAU, 2005, 36). The Defense Acquisition University was updating its contingency contracting curriculum at the time of our research.
18. GlobalSecurity.org, *Silver Flag*, [Online] Available: http://www.globalsecurity.org/military/ops/silver-flag.htm., last updated August 21, 2005. The Silver Flag exercises provide civil engineers, services, and other support personnel training on building and maintaining bare bases in deployed locations.
19. One or more contracts with regional providers that could easily distribute water to multiple locations would reduce the need for airlift.
20. Since the beginning of our study, USCENTAF Contracting and the USCENTAF Comptroller have introduced tools to address some of the data difficulties encountered in our analyses.
21. Laura H.Baldwin, John A. Ausink, Nancy F. Campbell, John G. Drew, and Charles Robert Roll, Jr, *Contingency Contracting Purchases for Operation Iraqi Freedom* (Unrestricted Version), Santa Monica, CA: RAND Corporation, MG-559/1-AF, 2008.

***Laura H. Baldwin**, PhD, is a senior economist at The RAND Corporation. She joined RAND in 1994 after completing a PhD in economics from Duke University. In 2007, she was named Director, Resource Management within Project Air Force. Prior to that, she was the associate director.*

***John Ausink**, PhD, is a senior policy researcher who has been at the RAND Corporation since 1999. He earned a BS in mathematics and physics from the United States Air Force Academy, an MS in mathematics from Oxford University, and a PhD in public policy from Harvard University. In the Air Force he was an instructor pilot in the T-37, T-41, and T-3A aircraft and an associate professor of mathematics at the Air Force Academy.*

***Nancy F. Campbell** is a senior programmer in the RAND Research Programming Department, providing programming support to the research staff. She has been at RAND since 1978. Her education includes a BA in psychology from the University of California, Los Angeles, CA. Ms Campbell has experience managing health data and has created numerous analytical files.*

***John G. Drew** is a senior project associate who has been at the RAND Corporation since 2002. Mr Drew has over 33 years experience in logistics systems operations, development, management, and evaluation. At RAND, he directs and conducts research to evaluate new logistics concepts, procedures, and systems needed to support the projection of aerospace power. Mr Drew has spent the last 10 years working projects evaluating how support policy, practice, and technology options impact the effectiveness and efficiency of air and space expeditionary forces. He retired from the Air Force as a chief master sergeant after 27 years of service.*

***C. Robert Roll**, Jr, PhD, was the Director, Resource Management for Project Air Force until 2006. He died in April 2007. A friend and mentor, he is truly missed.*

Beyond Aut
Aircraft

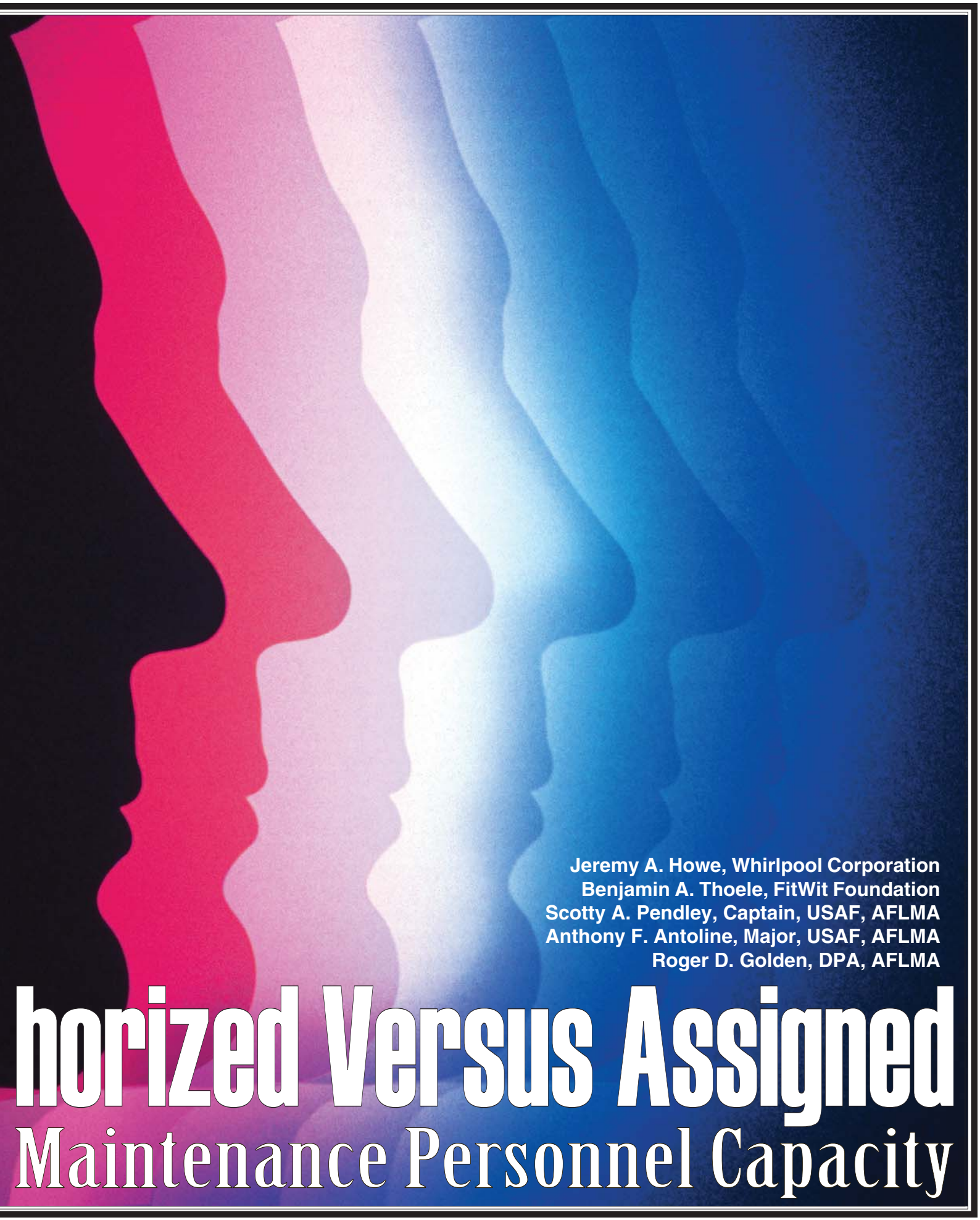
Introduction

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.

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



Jeremy A. Howe, Whirlpool Corporation
Benjamin A. Thoele, FitWit Foundation
Scotty A. Pendley, Captain, USAF, AFLMA
Anthony F. Antoline, Major, USAF, AFLMA
Roger D. Golden, DPA, AFLMA

horized Versus Assigned Maintenance Personnel Capacity

Article Highlights

Ultimately, the NEP methodology has the potential to be used alone or in conjunction with the Logistics Composite Model to better portray maintenance personnel requirements and capabilities based on experience and skill levels.

"Beyond Authorized Versus Assigned: Aircraft Maintenance Personnel Capacity" quantifies the phrase "we need more people" beyond the traditional metric of authorized versus assigned personnel. The article is based on work done for a recent Air Force Logistics Management Agency project—*C-5 TNMCM Study II*. During this project, an extensive, repeatable methodology was developed and utilized to scope an original list of 184 factors down to two potential root causes. 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 need, 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 viewpoint. The article describes how the NEP calculations were developed during the C-5 TNMCM Study 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.

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. 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 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 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 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

Article Highlights

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 NEP methodology described in the article is a repeatable process which produces data that provides 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. 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 the Logistics Composite Model to better portray maintenance personnel requirements and capabilities based on experience and skill levels.

This is the first in a three-part series of articles that examine C-5 TNMCM rates.

Article Acronyms

AFB – Air Force Base
AFLMA – Air Force Logistics Management Agency
AFSC – Air Force Specialty Code
AMXS – Aircraft Maintenance Squadron
ANGB – Air National Guard Base
APG – Aerospace and Powerplant General
CBT – Computer-Based Training
CMS – Component Maintenance Squadron
EMS – Equipment Maintenance Squadron
ETCA – Education and Training Course Announcement
LCOM – Logistics Composite Model
MXG – Maintenance Group
MXS – Maintenance Squadron
NEP – Net Effective Personnel
TDY – Temporary Duty
TNMCM – Total Not Mission Capable Maintenance

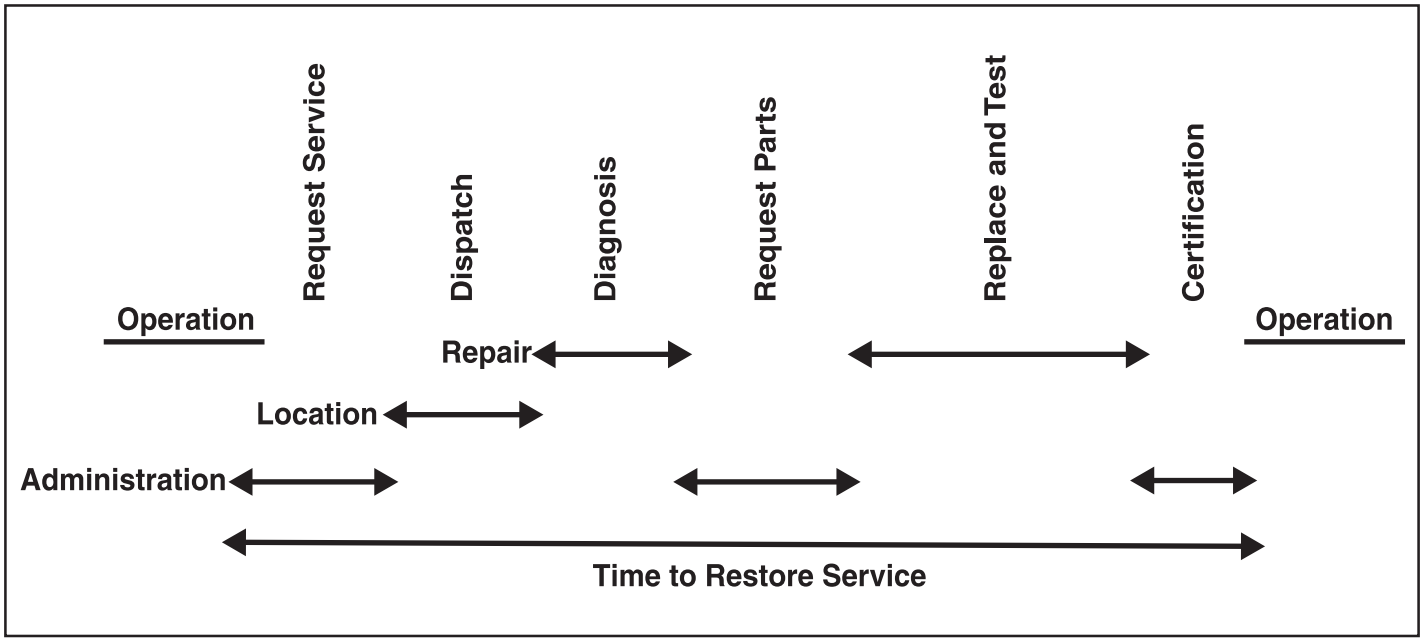


Figure 1. Time to Restore Service Process Model[10]

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]

important to consider three additional factors that introduce variability into the personnel resource pool. These factors are:

- 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.

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]

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 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 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.

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]

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

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]

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

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.

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

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 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.

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.

$$NEP = T_{75}(A_{75NT} + (P_t A_{75T})) + T_3(P_e A_3)$$

Equation 1. Net Effective Personnel

# of available 3-levels	30	CBT Factor (3-levels)	0.925
# of available 5-levels who are trainers	30	CBT Factor (5/7-levels)	0.948
# of available 5-levels who are **not** trainers	32	Productivity Factor (trainees)	0.400
# of available non-manager 7-levels who are trainers	0	Productivity Factor (trainers)	0.850
# of available non-manager 7-levels who are **not** trainers	12		
NEP		77.0	

Figure 3. Example NEP Calculation

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

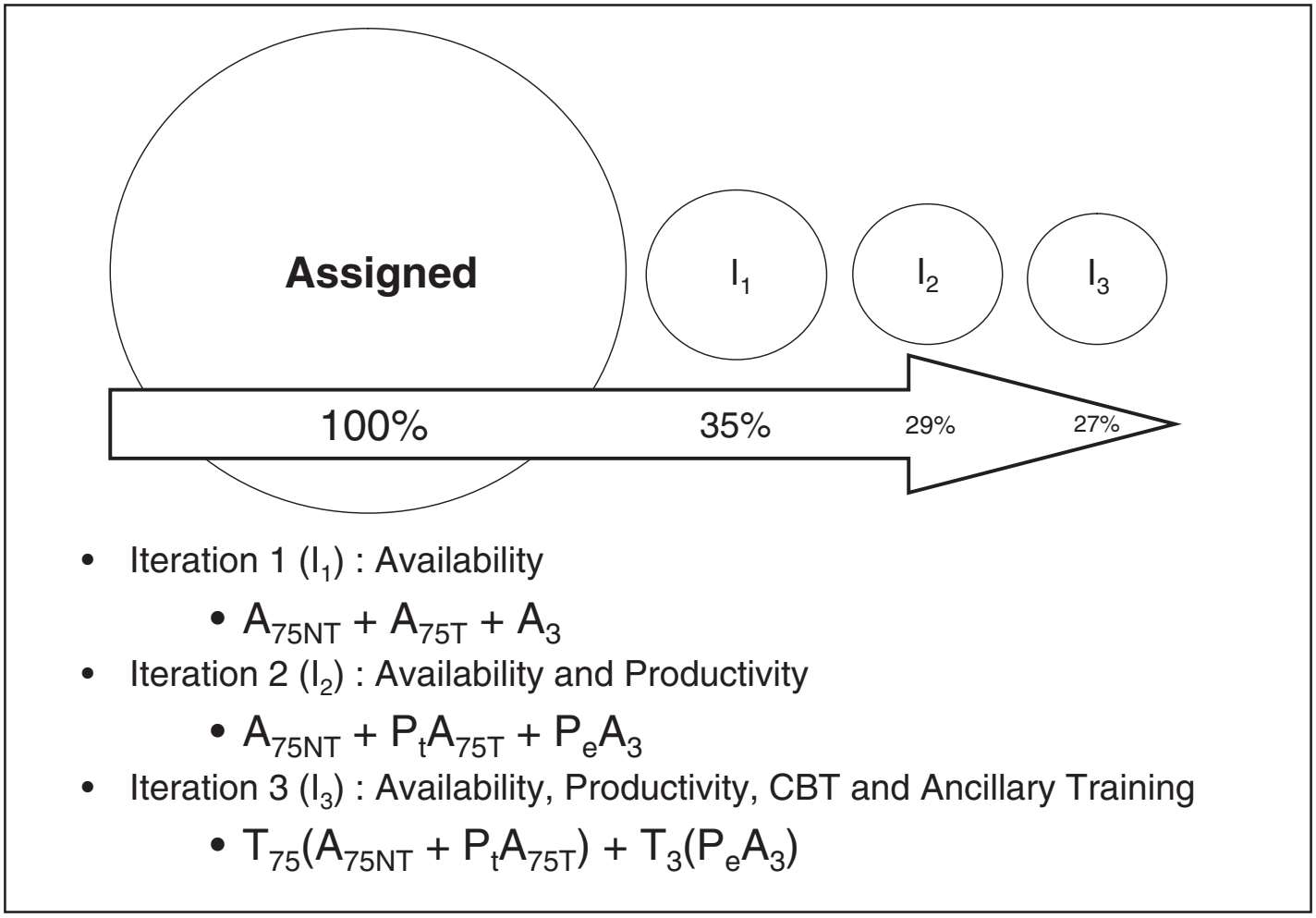


Figure 4. The Iterations of NEP

assigned technicians to MXS. This calculation yielded daily estimates of the number of NEP for MXS. Since AMXS 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 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/.

End Notes

1. General T. Michael Moseley, *CSAF's Vector: Air Mobility's Strategic Impact*, 23 May 2007, [Online] Available: http://www.af.mil/library/viewpoints/csaf.asp?id=324.
2. Honorable Michael W. Wynne and General T. Michael Moseley, "Strategic Initiatives," presentation to the House Armed Services Committee, 24 October 2007.
3. Michael W. Wynne, "Savings Less Than Expected in Drawdown," briefing to the Center for Strategic and Budgetary Assessments, *Air*

	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]

Force Times, [Online] Available: www.airforcetimes.com/news/2007/09/airforce wynnedrawdown 070924, accessed 9 September 2007.

4. AFI 21-101, *Aircraft and Equipment Maintenance Management*, HQ USAF/A4MM, 29 June 2006, 28.
5. Study team notes from 439 MXG daily production meeting, Westover ARB, 12 December 2006.
6. Study team notes from meeting with 436 MXG/CD, Dover AFB, 8 January 2007.
7. Study team notes from meeting with 105 MXG/CC, Stewart ANGB, 18 January 2007.
8. Carl J. Dahlman, Robert Kernchner, and Davis E. Thaler, *Setting Requirements for Maintenance Manpower in the US Air Force*, Santa Monica, California: RAND Corporation, 2002, 136.
9. J.R.T. Arnold and S. Chapman, *Introduction to Materials Management*, 5th ed., Pearson Education, 2003, 244.
10. Herbert Hecht, *Systems Reliability and Failure Prevention*, Norwood, MA: Artech House Inc., 2004.
11. John G. Drew, Kristin F. Lynch, Jim Masters, Robert S. Tripp, and Charles Robert Roll, Jr., *Maintenance Options for Meeting Alternative Active Associate Unit Flying Requirements*, Santa Monica, California: RAND Corporation, MG-611-AF, 2008.
12. *Ibid*.
13. *Ibid*.
14. *Ibid*.
15. *Ibid*.
16. Dahlman, et. al., 132.
17. This figure represents data from the 436 AMXS for March-April 2007.
18. "Ancillary Training," *Airman's Roll Call*, [Online] Available: http://www.af.mil/shared/media/document/AFD-070209-083.pdf, accessed 9 February 2007.
19. *Ibid*.
20. Study team notes from meeting with 436 MOS Supervision, 9 January 2007.
21. 436 AMXS/MXAA, Dover AFB, March – April 2007.
22. "Education and Training Course Announcement," ETCA Web site, [Online] Available: https://etca.randolph.af.mil/, accessed 21 March 2007.
23. *Ibid*.
24. US Office of Personnel Management, "Federal Holidays," [Online] Available: http://www.opm.gov/fedhol/, 11 April 2007.
25. It should be noted that the study team performed sensitivity analysis on the last three assumptions. See Table 3.
26. 436 AMXS/MXAA.
27. Data for 12 April 2007, 436 AMXS/MXAA, Dover AFB.
28. G/C is alternatively known as Automatic Flight Controls & Instruments.
29. 436 AMXS/MXAA.
30. *Ibid*.
31. Air Force Personnel Center, data pull, 27 March 2007.
32. Values in Table 7 are rounded to nearest whole number.

Jeremy A. Howe *is currently employed with the Whirlpool Corporation, Corporate Headquarters, as the Manager, North American Region Supply Chain Metrics Team. He previously worked as a Captain in the Air Force Logistics Management Agency as Chief, Munitions Analysis.*

Benjamin A. Thoele *is currently the Executive Director of the FitWit Foundation in Atlanta, Georgia. He previously worked as a Captain in the Air Force Logistics Management Agency as an operations researcher and Chief, Logistics Analysis.*

Major Scotty A. Pendley *is currently the Chief, Maintenance Studies Branch, Logistics Innovation Studies Division, Air Force Logistics Management Agency.*

Major Anthony F. Antoline *is currently the Chief, Logistics Logistics Transformation Division, Air Force Logistics Management Agency.*

Roger D. Golden *is the Director, Air Force Logistics Management Agency.*

Who bravely dares must sometimes risk a fall.

—Tobias George Smollett

Historical Perspective

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

—Field Marshal 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.

There are at least three general lessons from history that might prove of some use in understanding how best to prepare for the future. 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.

Colonel Karen S. Wilhelm, USAF (Ret)

Concentration and Logistics

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 as follows. Logistics is not independent. It exists only as one half of a partnership needed to achieve 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.

Wing Commander David J. Foster, RAF

Lessons from the First Deployment of Expeditionary Airpower

The lens of history speaks to many of the issues that are significant in today's expeditionary airpower environment. Particularly relevant are the lessons learned during first deployment of expeditionary airpower by the Royal Flying Corps during WWI. These include:

- The use of airpower is an expensive proposition.
- Maintaining aircraft away from home station demands considerable resources.
- Attrition from active operations is often very high.
- Effective support demands the ready availability of spares.
- Transport and protecting the transportation system is critical.
- Preserving mobility (the ability to redeploy quickly) is a constant battle.
- The supply system must be adequate in scope with a margin in capacity to meet unplanned events.
- The essential *lubricant* is skilled manpower.

Group Captain Peter J. Dye, RAF

Aligning

Introduction

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]

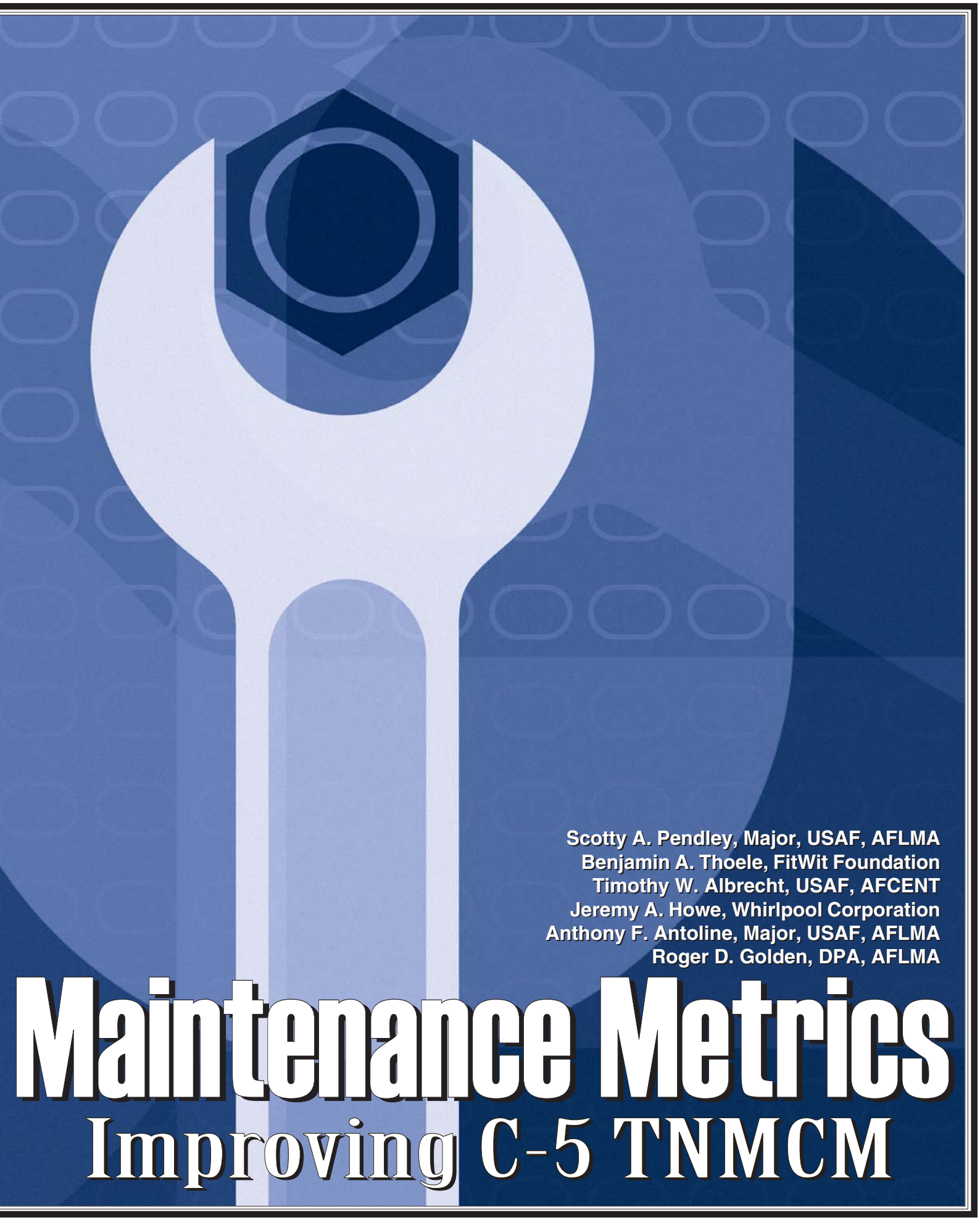
Dr Michael Hammer, a recognized leader in the field of process reengineering, also notes four principles of measurement.

- 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]

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



Scotty A. Pendley, Major, USAF, AFLMA
Benjamin A. Thoele, FitWit Foundation
Timothy W. Albrecht, USAF, AFCENT
Jeremy A. Howe, Whirlpool Corporation
Anthony F. Antoline, Major, USAF, AFLMA
Roger D. Golden, DPA, AFLMA

Maintenance Metrics

Improving C-5 TNMCM

Article Highlights

Realignment of metrics must start at the highest levels of the Mobility Air Force (MAF). The MAF should choose its value measure and create a set of metrics aligned with that measure.

At the request of the Air Force Materiel Command Director of Logistics, AFLMA conducted an analysis in 2006-2007 of total not mission capable maintenance (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 versus the 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 leadership's primary metric, home station logistics departure reliability (HSLDR), and one of the major command and Air Force senior leadership's primary metrics, aircraft availability. 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.

The research demonstrated that HSLDR is aligned with neither aircraft availability nor TNMCM, as there is only a weak correlation between them. Maintainers at the wing level work to support 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.

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 maintenance group (MXG) leadership focuses on HSLDR performance, not TNMCM, the MXP 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

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) x 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.

Article Highlights

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 leadership and MXG leadership decide on a set of metrics that are better aligned toward the same goal.

This is the second in a three-part series of articles that examine C-5 TNMCM rates.

Article Acronyms

AA – Aircraft Availability
AFB – Air Force Base
AFI – Air Force Instruction
AFLMA – Air Force Logistics Management Agency
AFMC – Air Force Materiel Command
AMC – Air Mobility Command
D&C – Delays and Cancellations
Est TNMCM – Estimated TNMCM
FIFO – First In First Out
FY – Fiscal Year
HS – Home Station
HSLDR – Home Station Logistics Departure Reliability
LDR – Logistics Departure Reliability
LIFO – Last In First Out
MAF – Mobility Air Force
MAJCOM – Major Command
MC – Mission Capable
MCO – Maintenance Carryovers
MCR – Mission Capable Rate
MDR – Maintenance Dispatch Reliability
MOS – Maintenance Operations Squadron
MX – Maintenance
MXG – Maintenance Group
MXP – Maintenance Priority
NMC – Not Mission Capable
NMCB – Not Mission Capable Both
NMCM – Not Mission Capable Maintenance
NMCS – Not Mission Capable Supply
REMIS – Reliability and Maintainability Information System
TDR – Technical Dispatch Reliability
TNMCM – Total Not Mission Capable Maintenance
UAOOS – Unscheduled Aircraft Out of Service

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 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.

	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

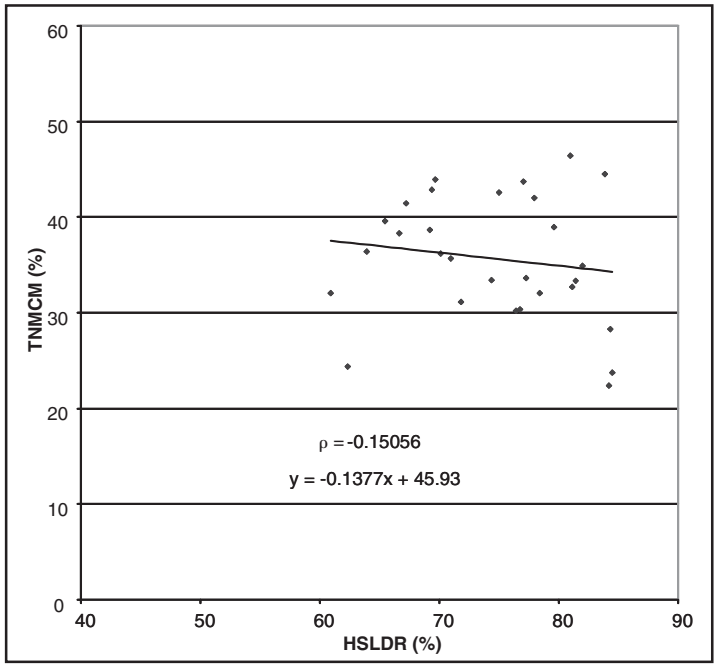


Figure 1. HSLDR and TNMCM Rates Scatter Plot for 436 MXG August 2004 to December 2006

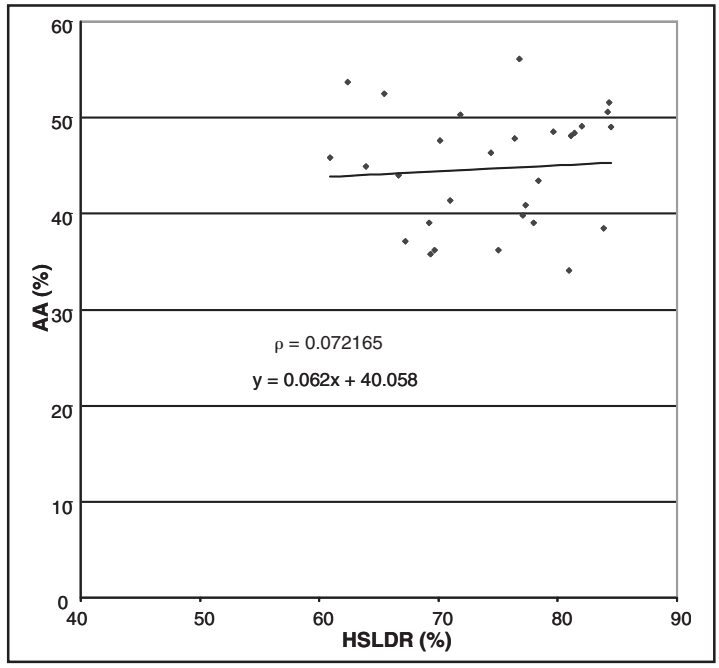


Figure 2. HSLDR and AA Rates Scatter Plot for 436 MXG August 2004 to December 2006

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 ρ = -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 ρ = 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 ρ = -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.

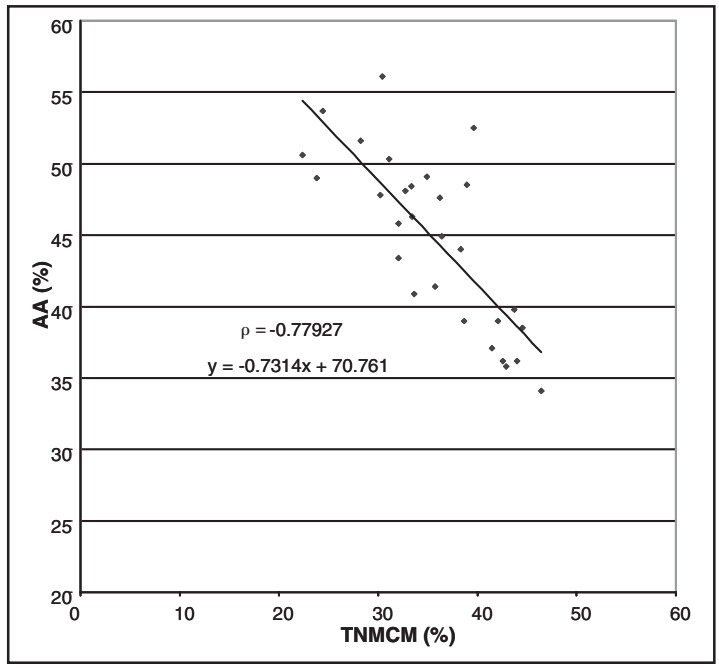


Figure 3. TNMCM and AA Rates Scatter Plot for 436th MXG August 2004 to December 2006

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 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.

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.

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 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

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

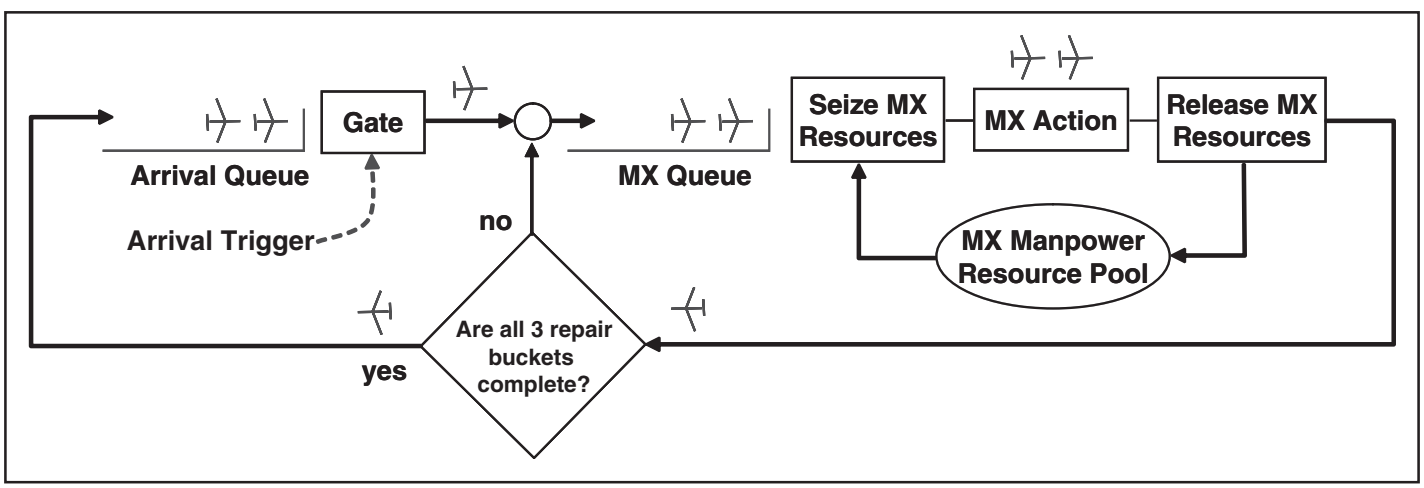


Figure 4. Maintenance Process as Modeled in the C-5 MXP Simulation

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

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]

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 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 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

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

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/.

Notes

1. AFLMA, *Metrics Handbook for Maintenance Leaders*, December 2001, 3.
2. AFLMA, 6.
3. AFI 21-101, *Aircraft and Equipment Maintenance Management*, 29 June 2006, 23.
4. *Ibid.*
5. Michael Hammer, *Harnessing the Power of Process,* personal presentation, 22 September 2006.
6. *Ibid.*
7. Study team notes from meeting with AMC/A4 and AMC/A9, Scott AFB, 1 December 2006.
8. Study team notes from in-progress review VTC with AFMC/A4, AMC/A4M, AF/A4MY, and OAS/XRA, VTC, 31 January 2007.
9. Study team notes from MXG Daily Production Meeting, 12 December 2006.
10. Study team notes from meeting with MXG leadership, 18 January 2007.
11. Study team notes from meetings with MXG leadership, 17-19 January 2007.
12. Study team notes from meeting with MXG leadership, 8 January 2007.
13. Study team notes from meeting with MXG leadership, 11 January 2007.
14. AFI 21-101, 27-28.
15. *Ibid.*
16. AFI 21-101, 433.
17. AFI 21-101, 24-25.
18. Hammer.
19. AFI 21-101, 26.
20. AFI 21-101, 28.
21. Jason Howe, *Using FleetFocus M5 for Practical Fleet Management*, PowerPoint presentation, 2007, 14.
22. Dennis D. Wackerly, et al, *Mathematical Statistics with Applications* 6th ed, Pacific Grove, CA: Duxbury/Thomas Learning, Inc, 2002, 250-251.
23. 60th MXG/CCC, "Recovery Maintenance Brief," Power Point presentation, Travis AFB, 20 July 2006, 20; and "Recovery Maintenance Bullet Background Paper," Word document, Travis AFB, 20 July 2006, 1.
24. Gregory Porter, ACSSS/GFWAC, "Recovery Centered Maintenance (RCM) Talking Paper," Robins AFB, 4 May 2007, 1.
25. Harold S. Balaban, et al, "A Simulation Approach to Estimating Aircraft Mission Capable Rates for the United States Air Force," *Proceedings of the 2000 Winter Simulation Conference*, 2000, 1035-1042.
26. Balaban, et al, 1037.
27. Balaban, et al, 1040.
28. Study team notes from meeting with MXG leadership, 18 January 2007.
29. *Ibid.*
30. Jim Hylton and Jeff Finken, Delta Airlines Reliability Program Office, telephone interview, 12 March 2007.
31. *Ibid.*
32. *Ibid.*
33. Hylton and Finken.
34. *Ibid.*
35 *Ibid.*
36. *Ibid.*
37. Delta Technical Operations, http://www.delta.com/business_programs_services/technical_operations/about_delta_techops/experience_awards/index.jsp, 8 May 2007.

Major Scotty A. Pendley *is currently the Chief, Maintenance Studies Branch, Logistics Innovation Studies Division, Air Force Logistics Management Agency.*

Benjamin A. Thoele *is currently the Executive Director of the FitWit Foundation in Atlanta, Georgia. He previously worked as a Captain in the Air Force Logistics Management Agency as an operations researcher and Chief, Logistics Analysis.*

Major Timothy W. Albrecht *is currently Chief, Operational Assessments, AFCENT/A3XL, Long Range Plans. He previously worked in the Air Force Logistics Management Agency as Chief Analyst.*

Jeremy A. Howe *is currently employed with the Whirlpool Corporation, Corporate Headquarters, as the Manager, North American Region Supply Chain Metrics Team. He previously worked as a Captain in the Air Force Logistics Management Agency as Chief, Munitions Analysis.*

Major Anthony F. Antoline *is currently the Chief, Logistics Logistics Transformation Division, Air Force Logistics Management Agency.*

Roger D. Golden *is the Director, Air Force Logistics Management Agency.*

Logistics…embraces not merely the traditional functions of supply and transportation in the field, but also war finance, ship construction, munitions manufacture, and other aspects of war economy.

—Lieutenant Colonel George C. Thorpe, USMC

Logistics comprises the means and arrangements which work out the plans of strategy and tactics. Strategy decides where to act, logistics brings the troops to that point.

—General Antoine Henri Jomini

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."[1] The same may be said of lightning quick 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.…"[2] 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.

Notes

1. Charles R. Shrader, *U.S. Military Logistics, 1607-1991, A Research Guide*, New York: Greenwood Press, 1992, 3.
2. Shrader, 9.

The Editors, *Air Force Journal of Logistics*

The Themes of US Military Logistics

From a historical perspective, ten major themes stand out in modern US military logistics.

- The tendency to neglect logistics in peacetime and expand hastily to respond to military situations or conflict.
- The increasing importance of logistics in terms of strategy and tactics. Since the turn of the century, logistical considerations increasingly have dominated both the formulation and execution of strategy and tactics.
- The growth in both complexity and scale of logistics in the 20th century. Rapid advances in technology and the speed and lethality associated with modern warfare have increased both the complexity and scale of logistics support.
- The need for cooperative logistics to support allied or coalition warfare. Virtually every war involving US forces since World War I has involved providing or, in some cases, receiving logistics support from allies or coalition partners. In peacetime, there has been an increasing reliance on host-nation support and burden sharing.
- Increasing specialization in logistics. The demands of modern warfare have increased the level of specialization among support forces.
- The growing tooth-to-tail ratio and logistics footprint issues associated with modern warfare. Modern, complex, mechanized, and technologically sophisticated military forces, capable of operating in every conceivable worldwide environment, require that a significant portion, if not the majority of it, be dedicated to providing logistics support to a relatively small operational component. At odds with this is the need to reduce the logistics footprint in order to achieve the rapid project of military power.
- The increasing number of civilians needed to provide adequate logistics support to military forces. Two subthemes dominate this area: first, unlike the first half of the 20th century, less reliance on the use of uniformed military logistics personnel and, second, the increasing importance of civilians in senior management positions.
- The centralization of logistics planning functions and a parallel effort to increase efficiency by organizing along functional rather than commodity lines.
- The application of civilian business processes and just-in-time delivery principles, coupled with the elimination of large stocks of spares.
- Competitive sourcing and privatization initiatives that replace traditional military logistics support with support from the private business sector.

The Editors, *Air Force Journal of Logistics*

Establishing C-5 TNMCM Standards

Scotty A. Pendley, Major, USAF, AFLMA
Benjamin A. Thoele, FitWit Foundation
Jeremy A. Howe, Whirlpool Corporation
Anthony F. Antoline, Major, USAF, AFLMA
Roger D. Golden, DPA, AFLMA

Selected Reading
Air Force Journal of Logistics

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.

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

Article Highlights

There are numerous implications for the complex, seemingly disjointed standards methodology that are problematic for the Air Force at the strategic, operational, and tactical levels.

At the request of the Air Force Materiel Command Director of Logistics, AFLMA conducted an analysis in 2006-2007 of total not mission capable maintenance (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 analyze the process for calculating and establishing TNMCM standards. This article details the analysis conducted in support of that particular study objective.

It is important to recognize that any discussion of TNMCM rates and standards must also include 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 the authors point out, 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 research demonstrates that 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 authors conclude by recommending that a repeatable methodology be developed to compute the TNMCM standard so that it:

- Reflects day-to-day minimum operational requirements
- Adjusts to fully mobilized force capabilities and surge mobility requirements
- Accounts for historic capabilities and fleet resources

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, 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.

Article Highlights

Article Acronyms

AA – Aircraft Availability
AAT – Aircraft Availability Target
AC – Aircraft
ACC – Air Combat Command
AE – Aeromedical Evacuation
AFB – Air Force Base
AFI – Air Force Instruction
AFLMA – Air Force Logistics Management Agency
AFMC – Air Force Materiel Command
AFRC – Air Force Reserve Command
AFSO21 – Air Force Smart Operations for the 21st Century
AMC – Air Mobility Command
ANG – Air National Guard
BE – Business Effort
CLS – Contract Logistics Support
CONOPS – Concept of Operations
CSAF – Chief of Staff, United States Air Force
DOC – Designed Operational Capability
DoD – Department of Defense
FMC – Fully Mission Capable
FY – Fiscal Year
GAO – Government Accountability Office
HQ – Headquarters
LMI – Logistics Management Institute
LRS – Logistics Readiness Squadron
MAJCOM – Major Command
MC – Mission Capable
MCS – Mobility Capabilities Study
MDS – Mission Design Series
MERLIN – Multi-Echelon Resource and Logistics Information Network
MICAP – Mission Capable
MRS – Mobility Requirements Study
NMCB – Not Mission Capable Both
NMCM – Not Mission Capable Maintenance
NMCS – Not Mission Capable Supply
O&M – Operations and Maintenance
OPR – Office of Primary Responsibility
PAA – Possessed Aircraft Authorized
PMC – Partially Mission Capable
REMIS – Reliability and Maintainability Information System
RERP – Reliability Enhancement and Re-Engining Program
TNMCM – Total Not Mission Capable Maintenance
TNMCS – Total Not Mission Capable Supply
TWCF – Transportation Working Capital Fund
UTE - Utilization

		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]

The three MC standard requirement algorithms are detailed in Equations 1, 2, and 3. Equation 1 is typically used with active duty aircraft fleets.

$$MC_{Std} = \left[\frac{12 \times UTE}{(1 - Attrition) \times (Turn\ Pattern) \times (Fly\ Days)}\right] + \left[\frac{Spares + MC_{SchdMX}}{PAA}\right]$$

Equation 1. MC Standard[8]

Where:

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 *goal 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.

$$MC_{ANG} = \left[\frac{\left[AC_{O\&M} + AC_{TWCF/BE/AE} + AC_{Ops} + Spares\right]}{AC_{Forecast}}\right]$$

Equation 2. MC Standard for ANG[10]

Where:

$AC_{O\&M}$ 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 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.

$$MC_{ARC} = \frac{(MC_{AFRC} \times PAA_{AFRC}) + (MC_{ANG} \times PAA_{ANG})}{PAA_{AFRC} + PAA_{ANG}}$$

Equation 3. MC Standard for ARC Fleet[11]

The MC standard for the AFRC (MC_{AFRC}) fleet is calculated using the standard 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.

$$TNMCS_{Std} = 1 - AAT$$

Equation 4. TNMCS Standard[12]

The aircraft availability target (AAT), ties the TNMCS standard to the funding 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.

$$AAT = Required\ MC + NMCM_{3\ year\ historical}$$

Equation 5. AAT Calculation[14]

Required MC is determined the same way that the Air Force active duty MC standard is determined.[15]

$NMCM_{3\ year\ historical}$ 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.

$$TNMCM_{Std} = 1 - (MC_{Std} + TNMCS_{Std}) + NMCB_{3\ yr\ historical}$$

Equation 6. TNMCM Standard[18]

$NMCB_{3\ yr\ historical}$ 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]

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 Of 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.

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):

$$\begin{aligned} MC_{ANG} &= \left[\frac{[AC_{O\&M} + AC_{TWCF/BE/AE} + AC_{Ops} + Spares]}{AC_{Forecast}}\right] \\ &= \left[\frac{[3.84 + 1.19 + 0.45 + 1.3]}{15}\right] \\ &= \left[\frac{[6.78]}{15}\right] = \left[\frac{7}{15}\right] = 0.47 \end{aligned}$$

ARC MC Standard (Equation 3):

$$\begin{aligned} MC_{ARC} &= \frac{(MC_{AFRC} \times PAA_{AFRC}) + (MC_{ANG} \times PAA_{ANG})}{PAA_{AFRC} + PAA_{ANG}} \\ &= \frac{(0.50 \times 40) + (0.47 \times 27)}{67} = 0.488 \approx 0.50 \end{aligned}$$

TNMCS Standard (Equation 4):

$$TNMCS_{Std} = 1 - AAT = 1 - 0.92 = 0.08$$

TNMCM Standard (Equation 6):

$$\begin{aligned} TNMCM_{Std} &= 1 - (MC_{Std} + TNMCS_{Std}) + NMCB_{3\ yr\ historical} \\ &= 1 - (0.50 + 0.08) + 0.08 \\ &= 0.50 \end{aligned}$$

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 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

	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]

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.

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.

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.

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 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

	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]

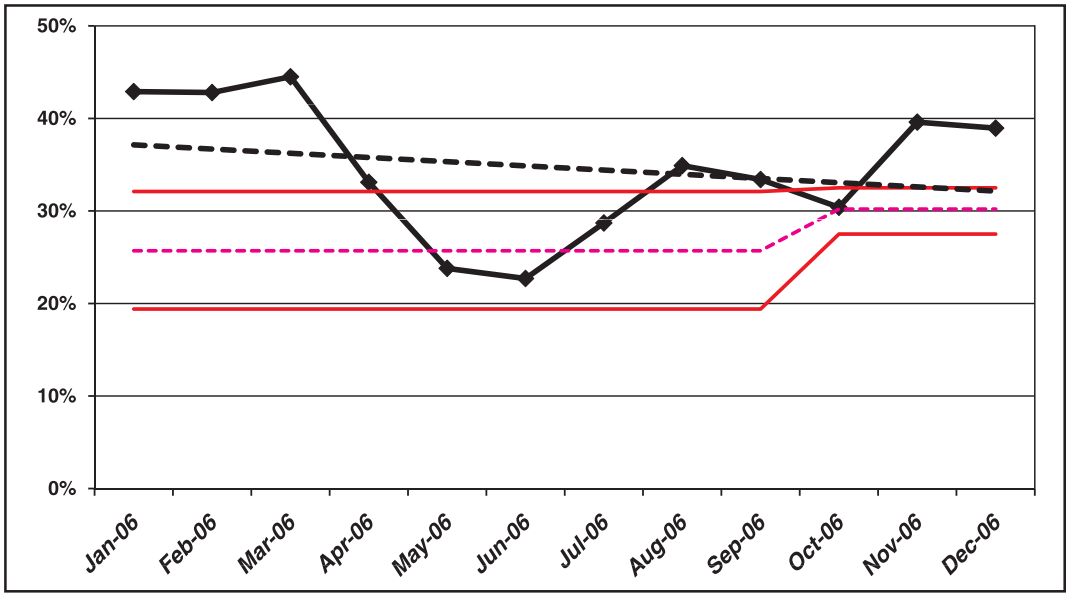


Figure 1. Example of TNMCM Control Chart, Dover AFB 2006[50]

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.

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 Air Force Journal of Logistics 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.

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/.

Notes

1. AFI 21-101, *Aircraft and Equipment Maintenance Management*, HQ USAF/A4MM, 29 June 2006, 27-28.
2. AFI 21-101, 28.
3. *Ibid*.
4. AF/A4MY, Metrics Chart with Air Staff Input, 6 February, Excel spreadsheet, 6 February 2007.
5. *Ibid*.
6. AF/A4MY, "C5 AFRC_ANG MC STD Explanation," e-mail, 11 May 2007.
7. AF/A4MY, 6 February 2007.
8. AF/A4MY, *C-5 Maintenance Standards Methodology*, PowerPoint presentation, 27 October 2006, 7-9.
9. AFI 21-101, 28.
10. AF/A4MY, 11 May 2007.
11. *Ibid*.
12. AF/A4MY, 27 October 2006, 3.
13. *Ibid*.
14. Logistics Management Institute, *Aircraft Availability Targets*, Report Number AF510T1, May 2006, 2-1.
15. Logistics Management Institute, 2-2.
16. AF/A4MY, 27 October 2006, 3.
17. Logistics Management Institute, 3-1.
18. AF/A4MY, 27 October 2006, 3.
19. Figures validated with MERLIN data; actual mean is 0.68 which is rounded to 0.7.
20. AF/A4MY, 11 May 2007.
21. AF/A4MY, 27 October 2006, 3.
22. AF/A4MY, 11 May 2007.
23. AF/A4MY, 27 October 2006, 2.
24. AMC/A4XM, FY 2007 Air Force Standards Data Call, Attachment 1, Excel spreadsheet, 7 February 2007.
25. Dave Merrill, AMC/A9, e-mail, 7 May 2007.
26. Joint Chiefs of Staff, *Mobility Requirements Study-05 Executive Summary*, Washington, DC: The Joint Staff, 23 January 1992, 5.
27. Dave Merrill, AMC/A9, telephone conference call, 8 May 2007.
28. *Ibid*.
29. Skip Tyler, AF/A4MY, telephone interview, 12 January 2007; AMC Metrics Handbook, 11.
30. AFI 21-101, 433.
31. General Accountability Office, *DOD Needs a Clear and Defined Process for Setting Aircraft Availability Goals in the New Security Environment*, Report Number GAO-03-300, April 2003.
32. GAO, executive summary.
33. *Ibid*.
34. GAO, 15.
35. GAO, 28.
36. *Ibid*.
37. The Air National Guard uses the term *goal* as opposed to *standard*. This information was obtained from a NGB/A4 Health of the Fleet, PowerPoint presentation, January 2007.
38. REMIS Data.
39. Personnel interviews, study team site visits, January 2007.
40. AFSO21 Concept of Operations, Version 1.0, 15 November 2006, 19. Taken from Dr Michael Hammer, Hammer and Company, Harnessing the Power of Process, 2006.
41. *Ibid*.
42. Study team site visits, personnel interviews, January 2007.
43. AFI 21-101, 23.
44. *Ibid*.
45. Thomas P. Ryan, *Statistical Methods for Quality Improvement*, Wiley & Sons, 2000, 77-134.
46. *Ibid*.
47. *Ibid*.
48. *Ibid*.
49. Study team site visits and personal interviews, Dover AFB and Westover ARB, January 2007.
50. Dover Air Force Base, Display Case MXG Metrics, PowerPoint presentation, 26 January 2007, slide 2.
51. CSAF Quarterly Review Slideshow, second quarter FY 2006, 31 March 2006.
52. Personal interview, AMC/A4XM, 10 May 2007.
53. *Ibid*.
54. Ryan, 82-86.
55. AMC/A44A, *Metrics Handbook for Mobility Air Forces*, 3d ed., April 2005, 7.
56. Ryan, 98.
57. Data Sources: *UTE, Spares, Required Mx MC, PAI*: FY07 Air Force Standards Data Call Spreadsheet, AF/A4MY. *Attrition, Turn rate*: Personnel interviews, Dover AFB. *NMCM 2 year historical, NMCB 3 year historical*: MERLIN data pull for AMC, FY04 – FY06, 15 May 2007.

Major Scotty A. Pendley *is currently the Chief, Maintenance Studies Branch, Logistics Innovation Studies Division, Air Force Logistics Management Agency.*

Benjamin A. Thoele *is currently the Executive Director of the FitWit Foundation in Atlanta, Georgia. He previously worked as a Captain in the Air Force Logistics Management Agency as an operations researcher and Chief, Logistics Analysis.*

Jeremy A. Howe *is currently employed with the Whirlpool Corporation, Corporate Headquarters as the Manager, North American Region Supply Chain Metrics Team. He previously worked as a Captain in the Air Force Logistics Management Agency as Chief, Munitions Analysis.*

Major Anthony F. Antoline *is currently the Chief, Logistics Logistics Transformation Division, Air Force Logistics Management Agency.*

Roger D. Golden *is the Director, Air Force Logistics Management Agency.*

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Selected Reading

Air Force Journal of Logistics

Stephen Hays Russell, PhD, Weber State University

Earned Value Management

uses and misuses

Originally developed as a financial management tool, earned value management (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, estimate at completion calculations with EVM metrics should be employed judiciously lest misleading projections arise given the circumstances of any particular project.

Introduction

Earned Value Management 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 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

Article Acronyms

ACWP – Actual Cost of Work Performed
BAC – Budget at Completion
BCWP – Budgeted Cost of Work Performed
BCWS – Budgeted Cost of Work Scheduled
CAP – Control Account Plan
CPI – Cost Performance Index
CV – Cost Variance
DoD – Department of Defense
EAC – Estimate at Completion
EVM – Earned Value Management
PBL – Performance Based Logistics
SPI – Schedule Performance Index
SV – Schedule Variance

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.

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 $Time_{now}$

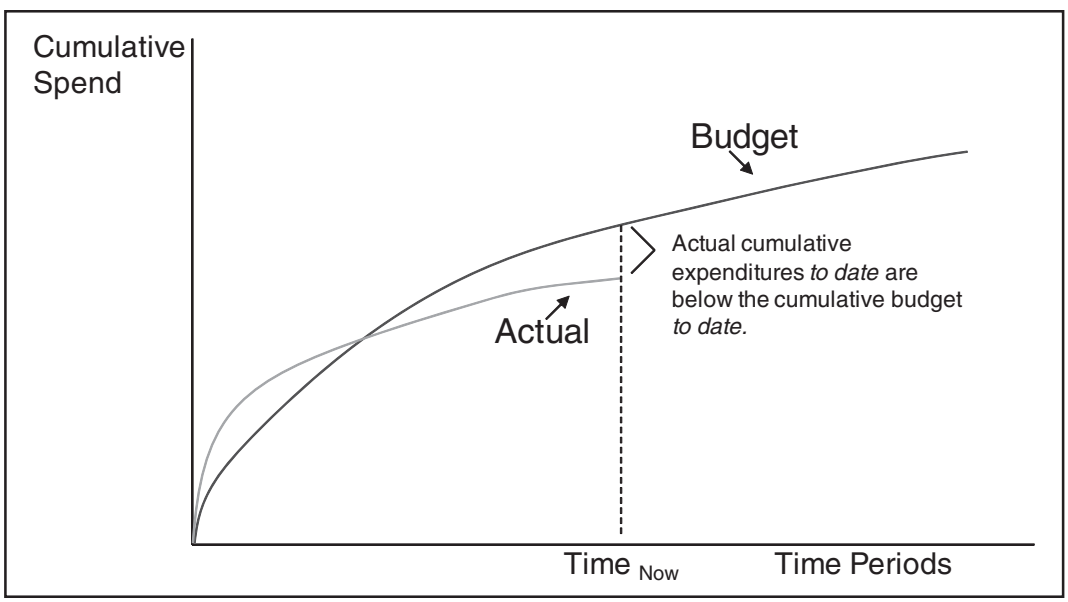


Figure 1. The Spend Plan Approach

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

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.

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.

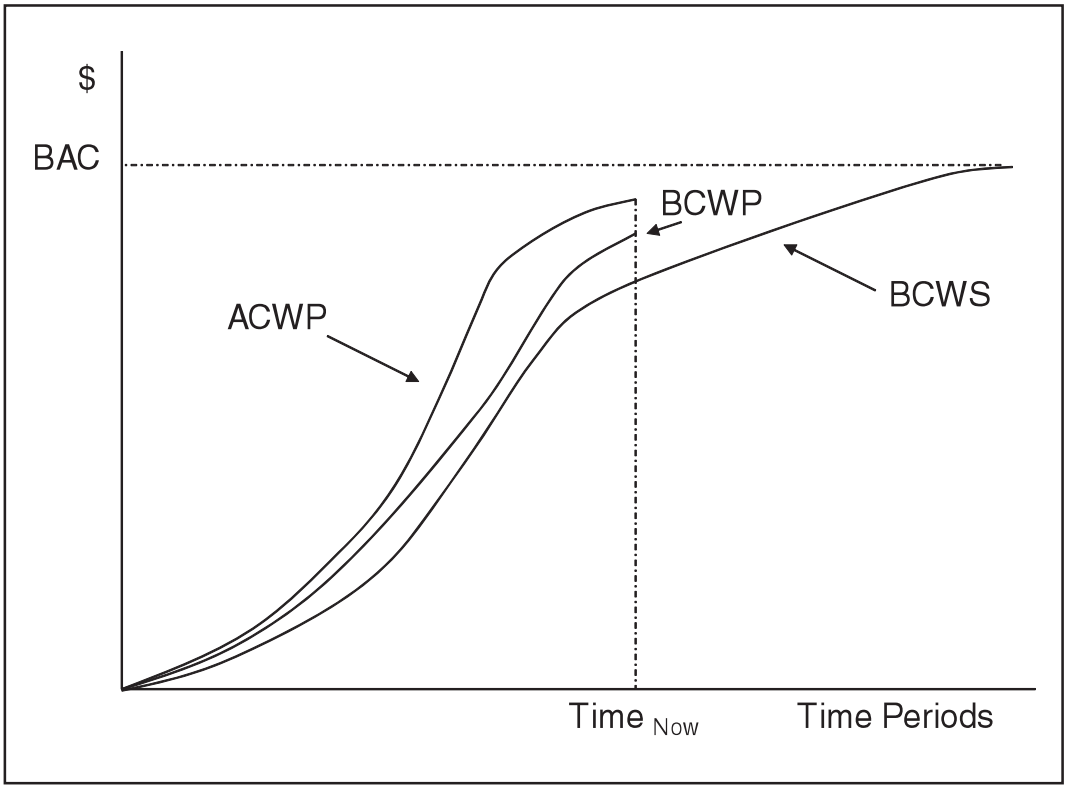


Figure 2. Illustration of EVM Metrics

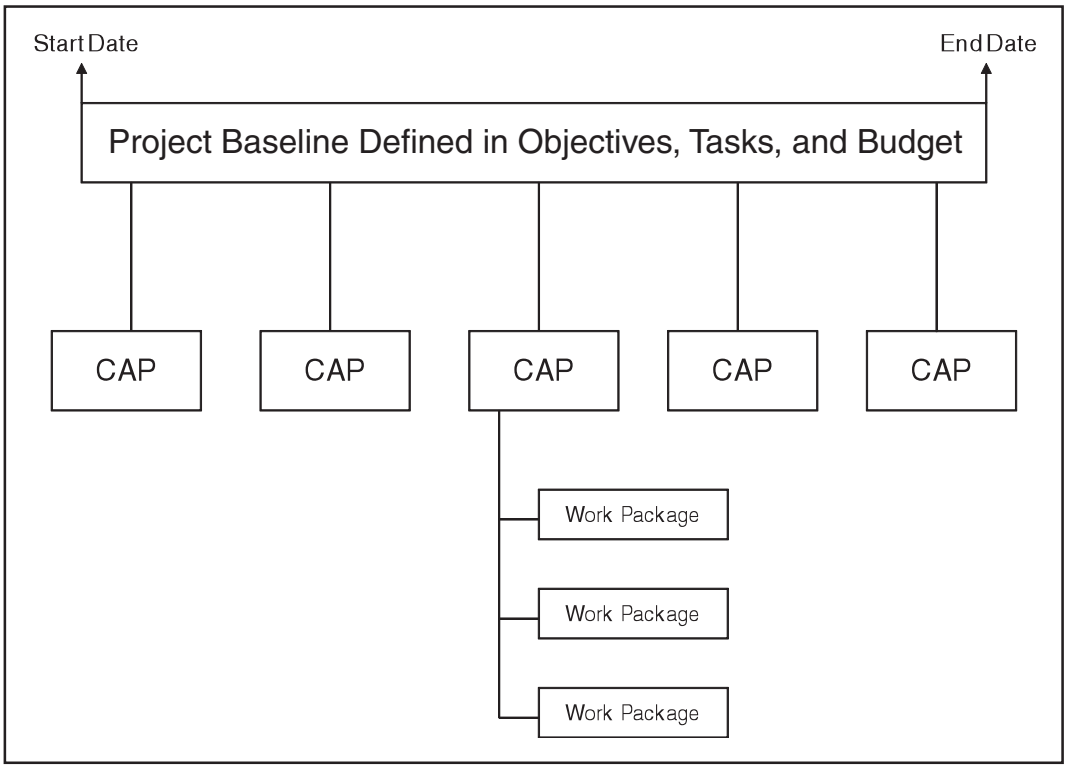


Figure 3. Data and Measurement Structure for Implementing EVM

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.

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.

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]

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.

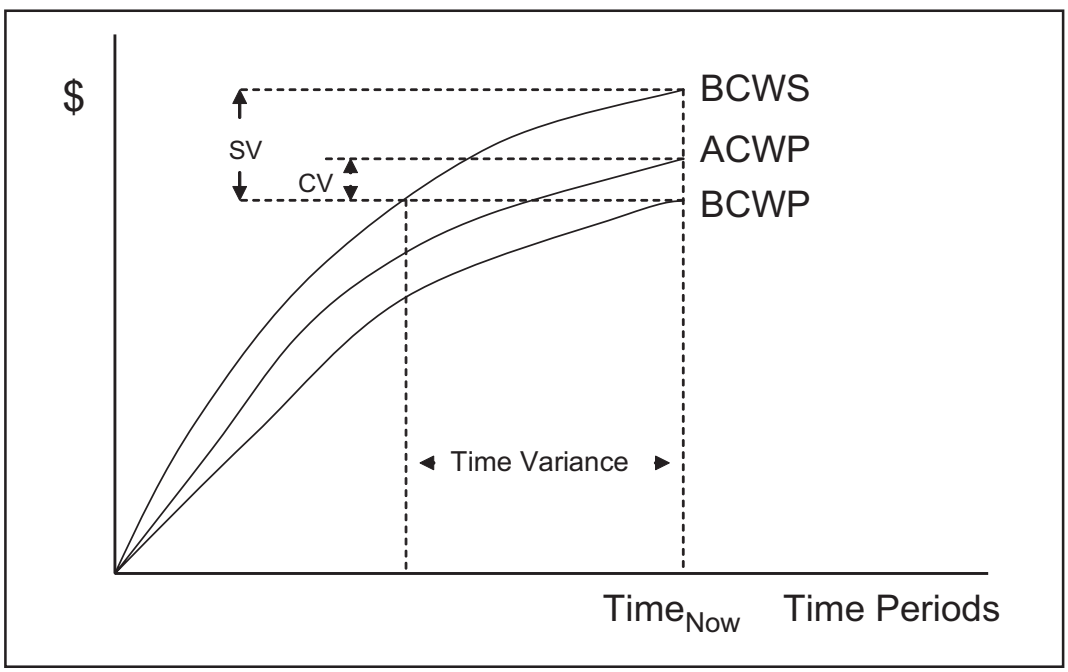


Figure 4. Performance Assessment with EVM Metrics

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, March 2005, [Online] Available: http://www.dau.mil/pubs/misc/PBL_Guide.pdf, accessed 28 April 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*, July 1998, 23, [Online] Available: http://www.stsc.hill.af.mil/crosstalk/1998/07/value.asp, accessed 11 November 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 April 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, October 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.

Lieutenant Colonel Stephen Hays Russell, PhD, USAF (Ret) *is Professor of Supply Chain Management, John B. Goddard School of Business and Economics, Weber State University, Ogden, Utah. His active duty assignments included logistics and acquisition management positions from base level to the Office of the Secretary of Defense. His areas of expertise include logistics, supply chain management, and systems acquisition strategies.*

If I had to sum up in a word what makes a good manager, I'd say decisiveness. You can use the fanciest computers to gather the numbers, but in the end you have to set a timetable and act.

—Lido Anthony (Lee) Iacocca

If opportunity doesn't knock, build a door.

—Milton Berle

No form of transportation ever really dies out. Every new form is an addition to, and not a substitution for, an old form of transportation.

—Air Marshal Viscount Hugh M. Trenchard, RAF

Selected Reading
Air Force Journal of Logistics

The Problem Is Big, Time Is Short,and Visibility Is Enormous

Using AFSO21

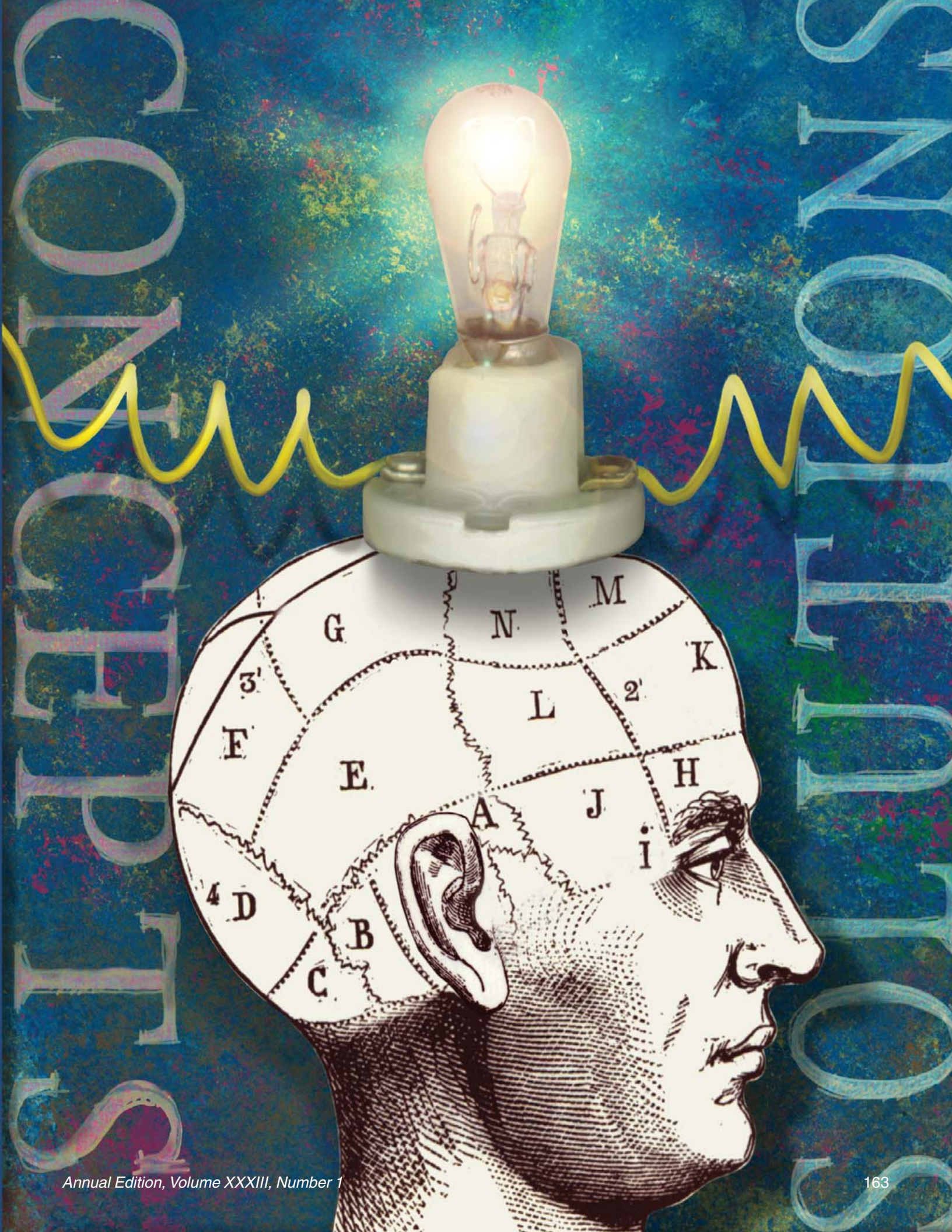
The foundation of the Comprehensive Assessment of Nuclear Sustainment (CANS) analysis was the aggressive use of Air Force Smart Operations for the 21st Century (AFSO21) tools to attack root causes. Though the effort was time constrained and many of the processes were modified to streamline the application, 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.

Major Jennifer G. Walston, PhD, USAF

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.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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:

- 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.
- **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

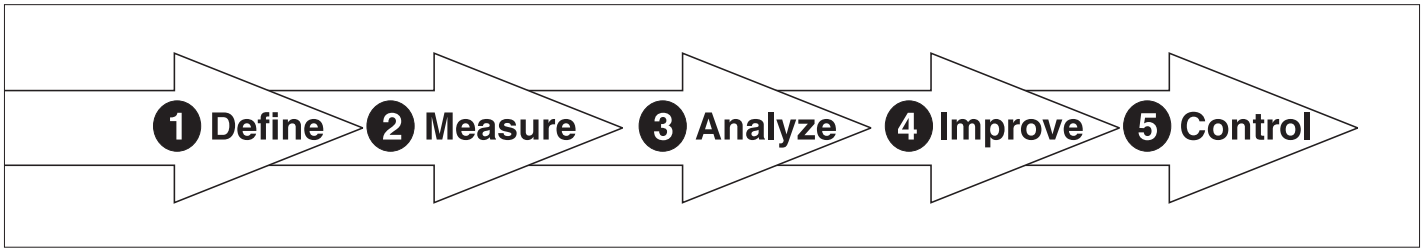

Figure 1. The DMAIC 5-Step Problem Solving Approach[5]

- 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.

- 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 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 environment, 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 indentifying 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 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.

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]

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

$$x \in \Omega = \{0,1)^n : g_i(x) \leq 0, \ \ i = 1,2,\ldots, M\}$$

where $F:\{0,1\}^n \longrightarrow R^J$, *is that of finding a solution* $x^n \in \Omega$ that optimizes the set of objectives $F = (F_1, F_2, \ldots, F_J)$ *in the sense that no other point* $y \in \Omega$ 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.

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

	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

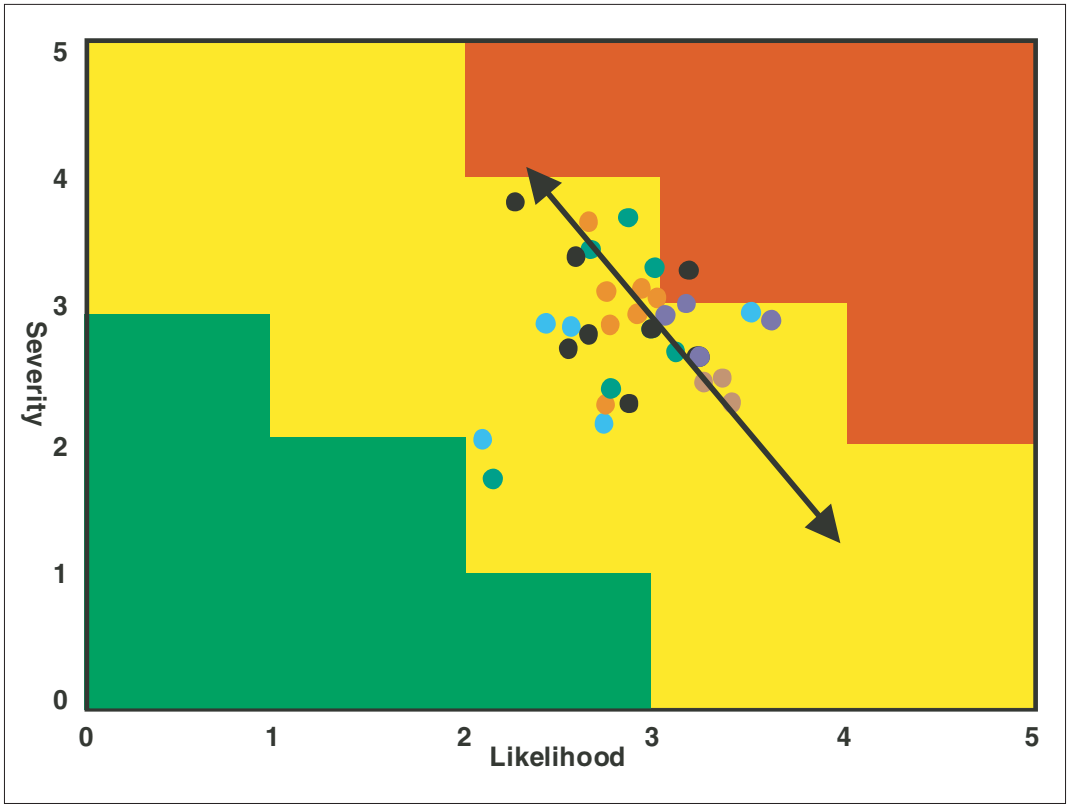

Figure 2. Notional Risk Analysis Output

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, 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.

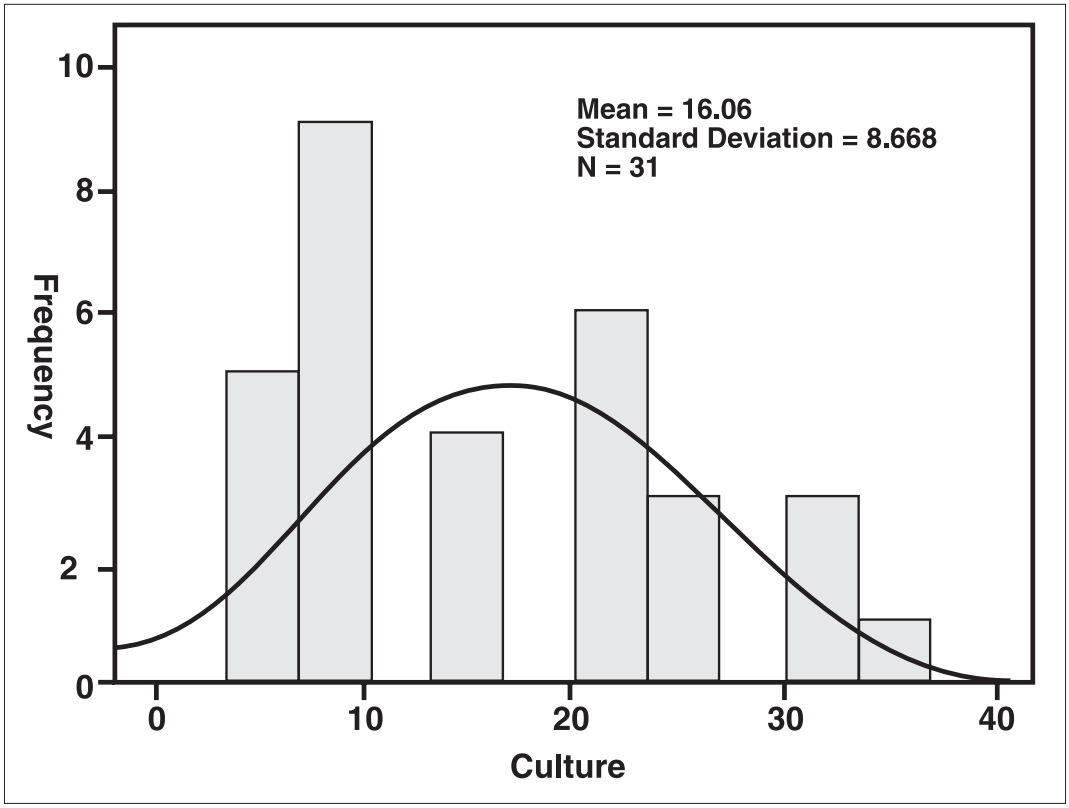

Figure 3. Histogram of Weights Assigned to Culture

Cost Analysis

The CANS cost team estimated costs for solutions

	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

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, time lines, 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.

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.

Notes

1. A. Abraham and J. Lakhmi, J. *Evolutionary Multiobjective Optimization,* London: Springer-Verlag, 2005.
2. AFMC PAM 63-101, *Risk Management*, 9 July 1997.
3. AFSO21 Level 1 Training, Lesson 4, Value Stream Mapping, accessed https://wwwd.my.af.mil/afknprod/ASPs/deskbook/index2.asp?Filter=OO-21&Type=DP&Cat=21, 27 June 2008.
4. AFSO21 Level 1 Training, Lesson 7, *Problem Solving Tools*, [Online] Available: https://wwwd.my.af.mil/afknprod/ASPs/deskbook/index2.asp?Filter=OO-21&Type=DP&Cat=21, 27 June 2008.
5. AF/SAO, *Air Force Smart Operations for the 21st Century Playbook*, Version 2.0, Volume H, H-2, [Online] Available: https://wwwd.my.af.mil/afknprod/ASPs/docman/DOCMain.asp?Tab=0&FolderID=OO-TR-AF-43-13&Filter=OO-TR-AF-43, October 2007.
6. Y. Collette, and P. Siarry, *Multiobjective Optimization Principles and Case Studies*, Berlin, Germany: Springer-Verlag, 2004.
7. I. Das and J. D. Dennis, Jr, "A Closer Look at Drawbacks of Minimizing Weighted Sums of Objectives for Pareto Set Generation in Multicriteria Optimization Probems, *Structural Optimization*, 1997, 14, 63—69.
8. M. Ehrgott, *Multicriteria Optimization,* second edition, Berlin, Germany: Springer, 2005.
9. Y. Fu and U. Diwekar, "An Efficient Sampling Approach to Multiobjective Optimization," *Annals of Operations Research*, 132, 109—134, 2004.
10. M. L. George, D. Rowlands, M. Price, and J. Maxey, *Lean Six Sigma Pocket Toolbook, a Quick Reference Guide to Nearly 100 Tools for Improving Process Quality, Speed, and Complexity*, New York, NY: McGraw-Hill, 2005.
11. T. Goldsby and R. Martichenko, *Lean Six Sigma Logistics, Strategic Development to Operational Success*, Fort Lauderdale, Florida: J. Ross Publishing, Inc., 2005.
12. SixSigma Magazine, term definition library. accessed http://www.isixsigma.com/dictionary/glosary.asp, 27 June 2008.
13. J. Jackson and M. Hailstone, "D&SWS Life Cycle Risk Management (LCRM) Update," briefing, D&SWS Core Process Working Group, 27 Jun 2008.
14. J. Kindinger and J. Darby, "Risk Factor Analysis—A New Qualitative Risk Management Tool," *Proceedings of the Project Management Institute Annual Seminars & Symposium*, Houston, Texas, 7-16 September 2000.
15. L. H. Lee, E. P. Chew, and S. Teng, "Optimal computing budget allocation for multi-objective simulation models," in J.S.S.R.G. Ingalls, M. D. Rossetti and B. A. Peters, editors, *Proceedings of the 2004 Winter Simulation Conference*, [Online] Available: http://www.informs-sim.org/wsc04papers/071.pdf.
16. M. Makowski, "Methodology and a Modular Tool for Multiple Criteria Analysis of lp Models," working papers, Laxenburg, Austria: International Institute for Applied Systems Analysis, 94-102.
17. S. Sait and H. Youssef, *Iterative Computer Algorithms with Applications in Engineering: Solving Combinatorial Optimization Problems*, Las Alamitos, California: IEEE Computer Society, 1999.
18. P. Vincke, *Multicriteria Decision-Aid*, England:John Wiley & Sons, 1992.
19. J. Walston, *Search Techniques for Multi-Objective Optimization of Mixed Variable Systems Having Stochastic Responses*, PhD thesis, Air Force Institute of Technology, September 2007.

Major Jennifer G. Walston, PhD, *is currently the Chief Scientist, Air Force Logistics Management Agency, Maxwell AFB, Gunter Annex, Alabama. At the time of writing this article, she was temporarily assigned to the Comprehensive Assessment of Nuclear Sustainment project at Hill Air Force Base, Utah.*

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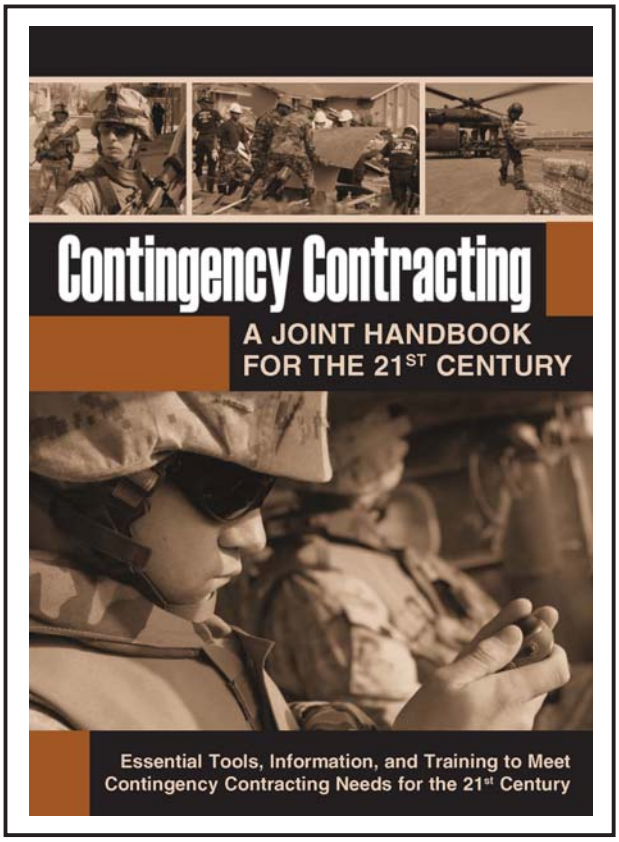
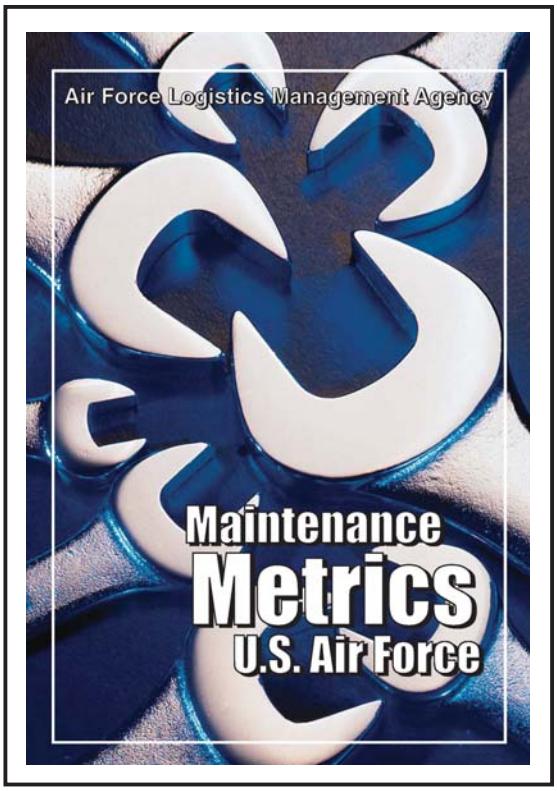


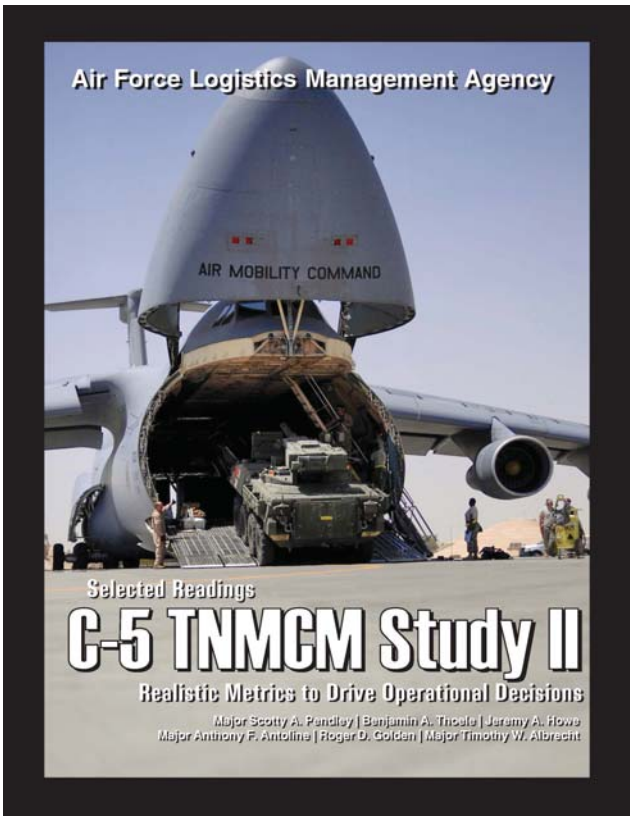
contingency contracting

Contingency contracting support has evolved from purchases under the simplified acquisition threshold to major defense procurement and interagency support of commodities, services, and construction for military operations and other emergency relief. Today, this support includes unprecedented reliance on support contractors in both traditional and new roles. Keeping up with these dramatic changes, while fighting the Global War on Terror, is an ongoing challenge. This pocket-sized handbook and its accompanying DVD provide the essential information, tools, and training for contracting officers to meet the challenges they will face, regardless of the mission or environment.

maintenance metrics

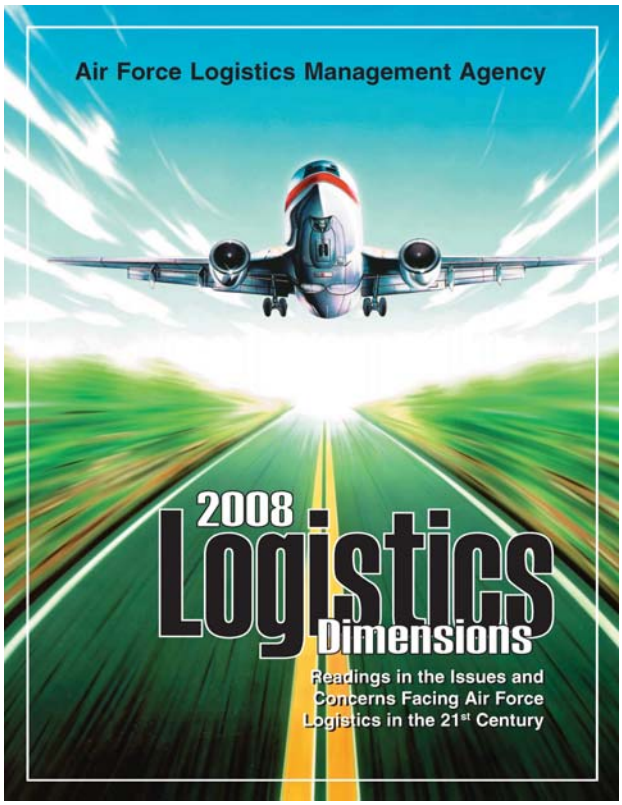
This handbook is an encyclopedia of metrics and includes an overview to metrics, a brief description of things to consider when analyzing fleet statistics, an explanation of data that can be used to perform analysis, a detailed description of each metric, a formula to calculate the metric, and an explanation of the metric's importance and relationship to other metrics. The handbook also identifies which metrics are leading indicators (predictive) and which are lagging indicators (historical). It is also a guide for data investigation.





C-5 TNMCM study II

The *C-5 TNMCM Study II* proved to be a stern test of AFLMA's abilities and perseverance. The research addressed areas of concern including maintaining a historically challenged aircraft, fleet restructuring, shrinking resources, and the need for accurate and useful metrics to drive desired enterprise results. The study team applied fresh perspectives, ideas and transformational thinking. They developed a new detailed methodology to attack similar research problems, formulated a new personnel capacity equation that goes beyond the traditional authorized versus assigned method, and analyzed the overall process of setting maintenance metric standards. A series of articles was produced that describes various portions of the research and accompanying results. Those articles are consolidated in this book.



logistics dimensions 2008

Logistics Dimensions 2008 is a collection of 19 essays, articles, and vignettes that lets the reader look broadly at a variety of logistics concepts, ideas, and subjects. Included in the volume is the work of many authors with diverse interests and approaches. The content 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 dimensions of logistics.

Have you noticed there seems to be a void when it comes to books or monographs that address current Air Force logistics thought, lessons from history, doctrine, and concerns? We did, and we're filling that void. Our staff produces and publishes selections of essays or articles—in monograph format—on a quarterly basis. Each has a theme that's particularly relevant to today's Air Force logistics. Informative, insightful, and in many cases, entertaining, they provide the Air Force logistics community the kind of information long taken for granted in other parts of the Air Force.

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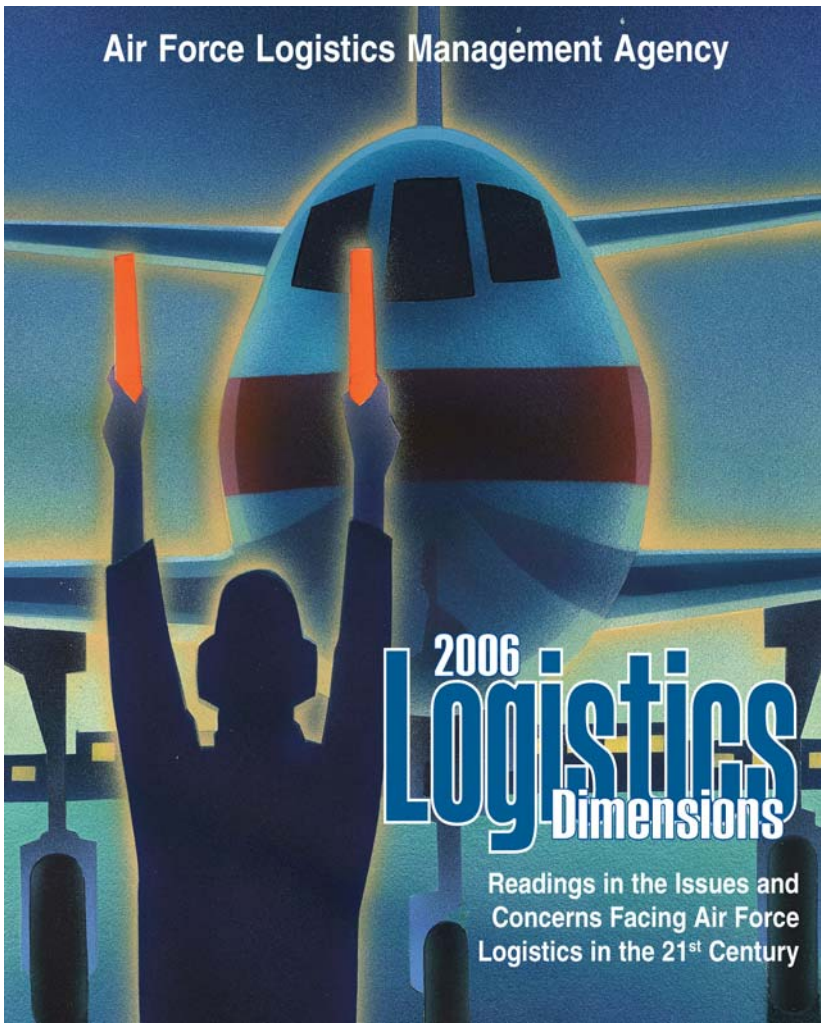
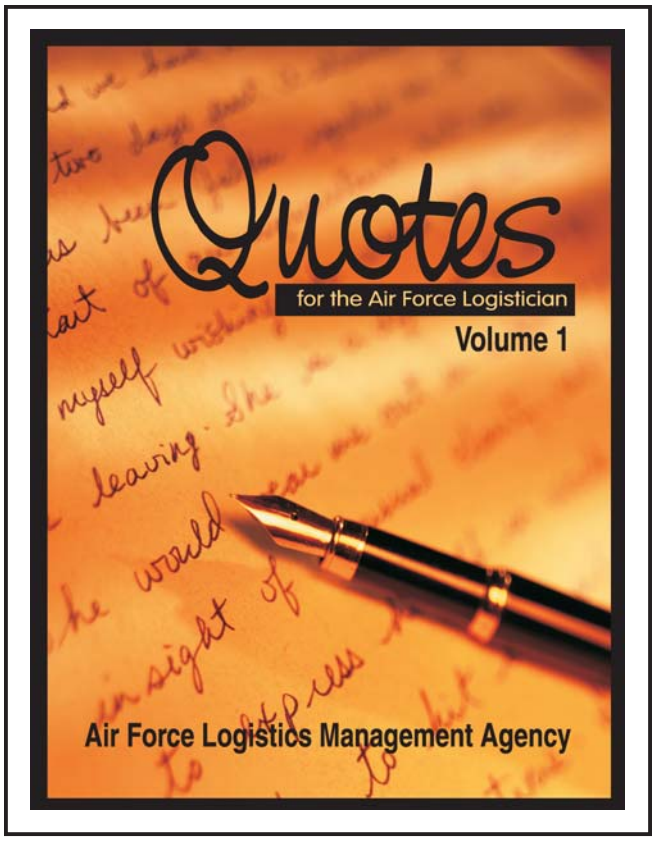


2006 logistics dimensions

Logistics Dimensions 2006 is a collection of 25 essays, articles, and vignettes that lets the reader look broadly at a variety of logistics concepts, ideas, and subjects. Included in the volume is the work of many authors with diverse interests and approaches. The content 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 dimensions of logistics. 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.

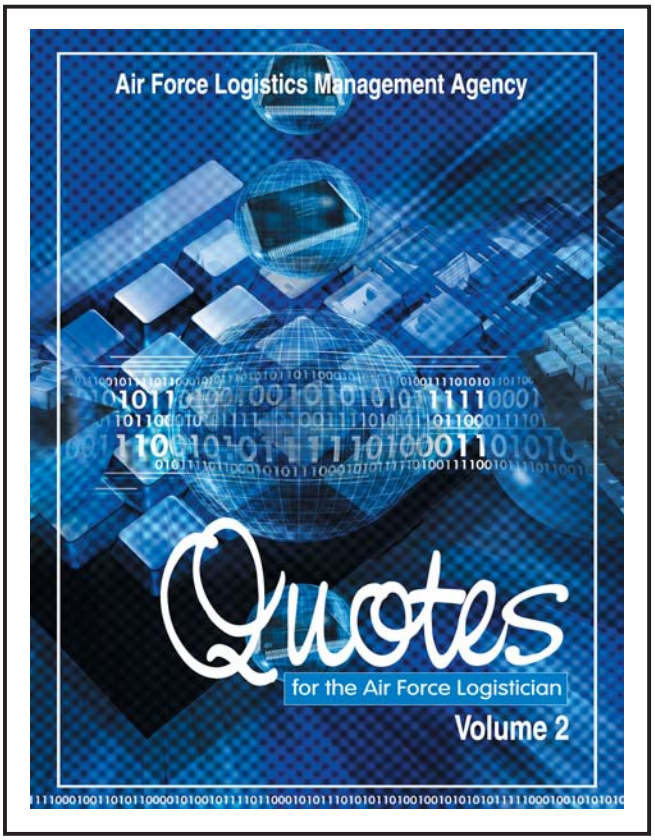


quotes for the Air Force logistician, volume 1

Quotes for the Air Force Logistician, Volume 1 is a teaching resource that can be used in classroom, education, training, and mentoring programs for Air Force logisticians. It is a tool that can be used by instructors, teachers, managers, leaders, and students. It is also a tool that can be used in research settings and a resource that should stimulate comment and criticism within educational and mentoring settings. Copies of the book are provided free of charge to any Air Force logistician, educational institution, teacher, instructor, commander, or manager. *Quotes for the Air Force Logistician, Volume 1* is packaged with *Quotes for the Air Force Logistician, Volume 2* as a boxed set.

quotes for the Air Force logistician, volume 2

Quotes for the Air Force Logistician, Volume 2 is a teaching resource that can be used in classroom, education, training, and mentoring programs for Air Force logisticians. It is a tool that can be used by instructors, teachers, managers, leaders, and students. It is also a tool that can be used in research settings and a resource that should stimulate comment and criticism within educational and mentoring settings. Copies of the book are provided free of charge to any Air Force logistician, educational institution, teacher, instructor, commander, or manager. *Quotes for the Air Force Logistician, Volume 2* is packaged with *Quotes for the Air Force Logistician, Volume 1* as a boxed set.



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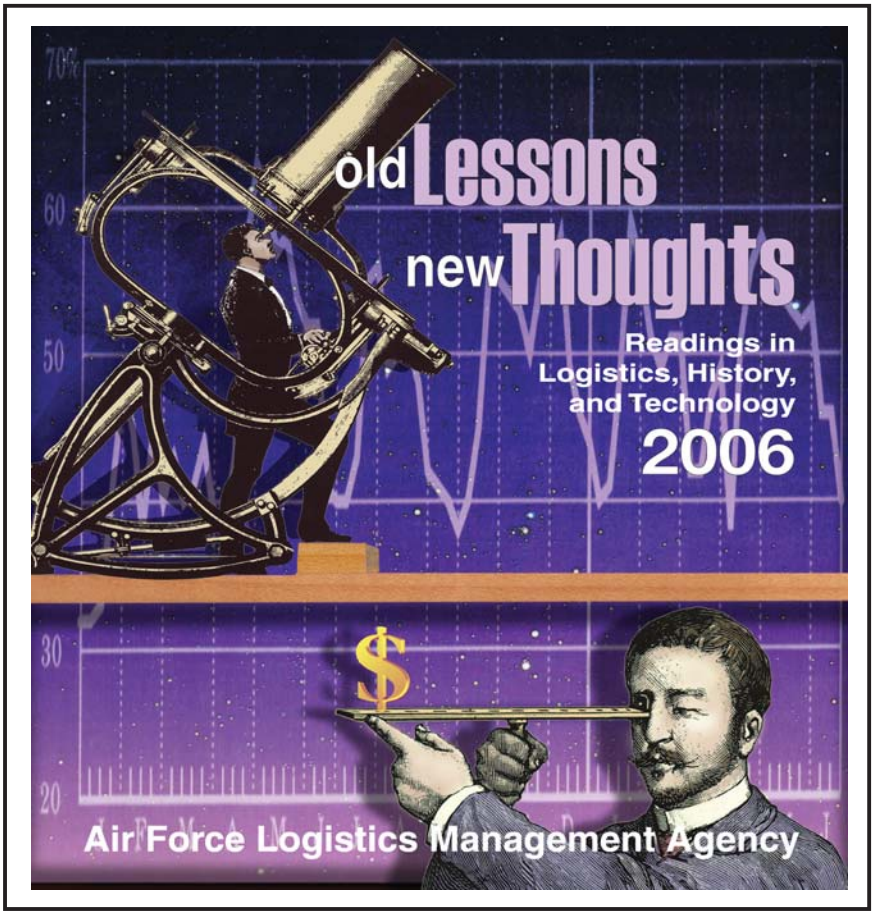
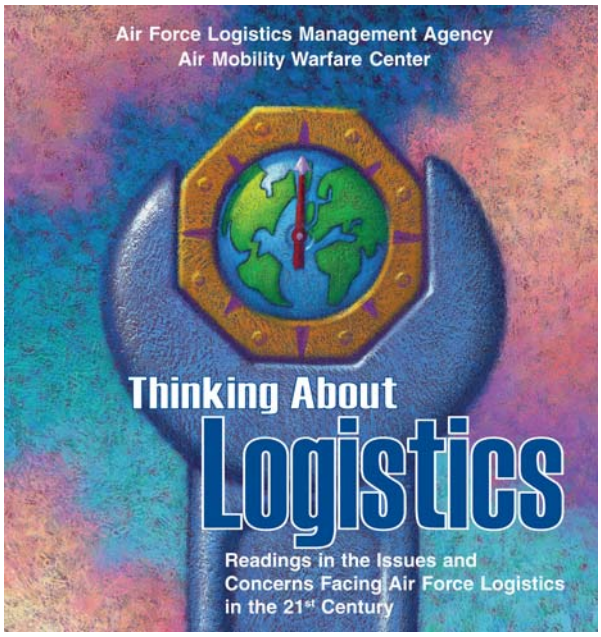
Each of our newest works is produced in a high-impact format that makes you *want* to pick it up and read it. If you're used to seeing or thinking of works dealing with logistics as colorless and dry, you'll be more than surprised with these products. They continue the tradition of high-quality publications produced by the Air Force Logistics Management Agency and staff of the Air Force Journal of Logistics.



old lessons new thoughts 2006

Old Lessons New Thoughts 2006 is a collection of 28 essays, articles, and vignettes that lets the reader look broadly at a variety of logistics and technological areas through the lens of history. Included in the volume is the work of many authors with diverse interests and approaches. The content was selected for two basic reasons—to represent the diversity of ideas and to stimulate thinking.

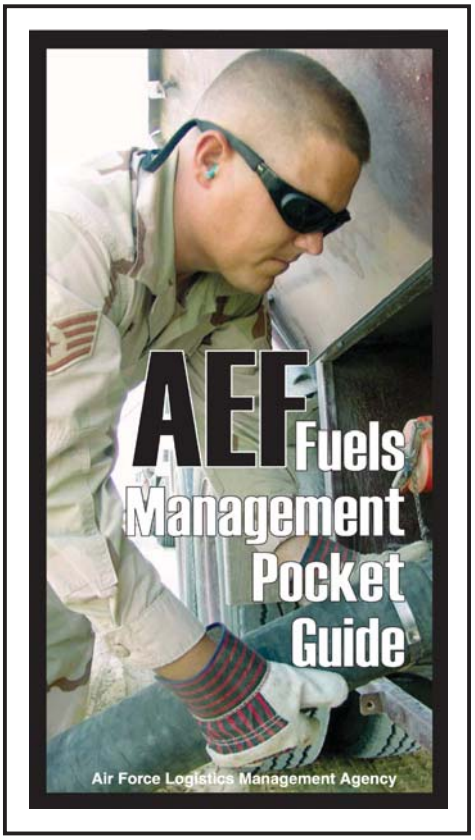


thinking about logistics

Thinking About Logistics is a collection of papers written by students taking the Advanced Logistics Readiness Officer Course at the Air Mobility Warfare Center, Fort Dix, New Jersey. The focus of the work is on issues facing Air Force logistics in the 21st century, particularly supporting expeditionary airpower.

aef fuels management pocket guide

The *AEF Fuels Management Pocket Guide* is designed to assist in understanding fuels issues as they relate to expeditionary airpower operations. The information is intended to provide a broad overview of many issues and be useful to anyone who has an interest in the Air Force fuels business.



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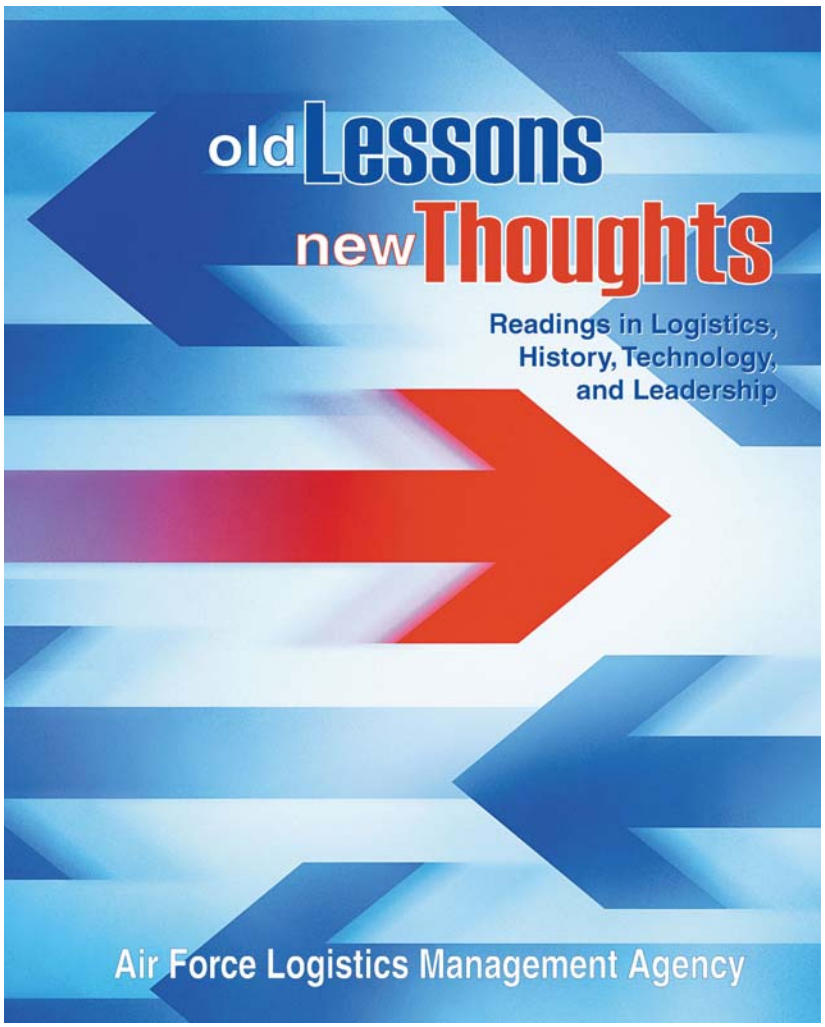
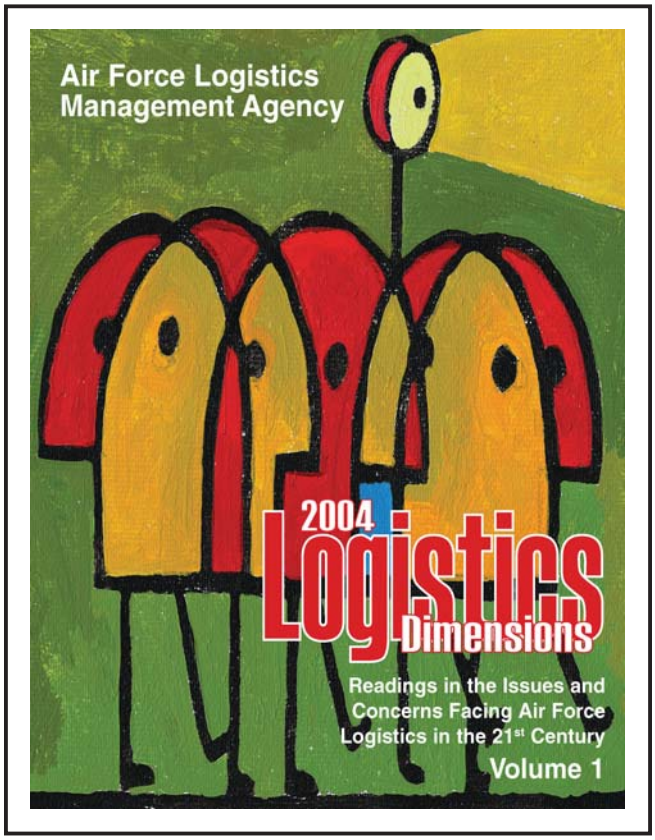


old lessons, new thoughts

Old Lessons, New Thoughts is a collection of seven essays or articles that lets the reader examine logistics and technological lessons from history that are particularly applicable in today's transformation environment. The majority of the articles and essays are the result of work done at the Air Command and Staff College during 2002 and 2003. Specific subject areas include oil logistics in the Pacific during World War II, German wonder weapons and logistics failings, advanced technology and modern warfare, leading the "nexters" generation, and Allied failings during the battle of the Kaserine Pass.

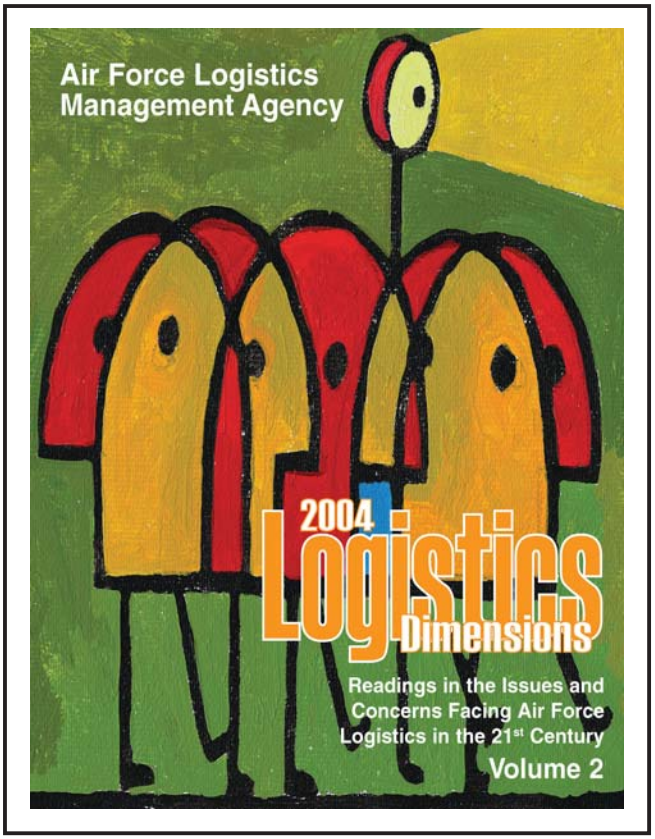


2004 logistics dimensions, volume 1

Logistics Dimensions 2004 is a two-volume collection of essays and articles that looks at a broad range of logistics challenges facing the Air Force in the 21st Century. Four major themes dominate the work presented—agile combat support (ACS), global support and mobility, supporting and maintaining aircraft, and contractor support and its implementation and implications. All the major articles and essays are the result of work done at the Air War College during 2003 and 2004. Specific subject areas included in Volume 1 include ACS, bare-base support in the ACS framework, global combat support systems, reducing the logistics footprint within the ACS framework, transformation, defense industrial base, global and theater mobility, and transportation technology implementation.

2004 logistics dimensions, volume 2

Logistics Dimensions 2004 is a two-volume collection of essays and articles that looks at a broad range of logistics challenges facing the Air Force in the 21st Century. Four major themes dominate the work presented—agile combat support, global support and mobility, supporting and maintaining aircraft, and contractor support and its implementation and implications. All the major articles and essays are the result of work done at the Air War College during 2003 and 2004. Specific subject areas included in Volume 2 include supporting aging aircraft, integrating active Air Force and Reserve units, recapitalizing tanker aircraft, aircraft modification versus new aircraft procurement, contractor support and contractors on the battlefield, and financial management as a force multiplier.



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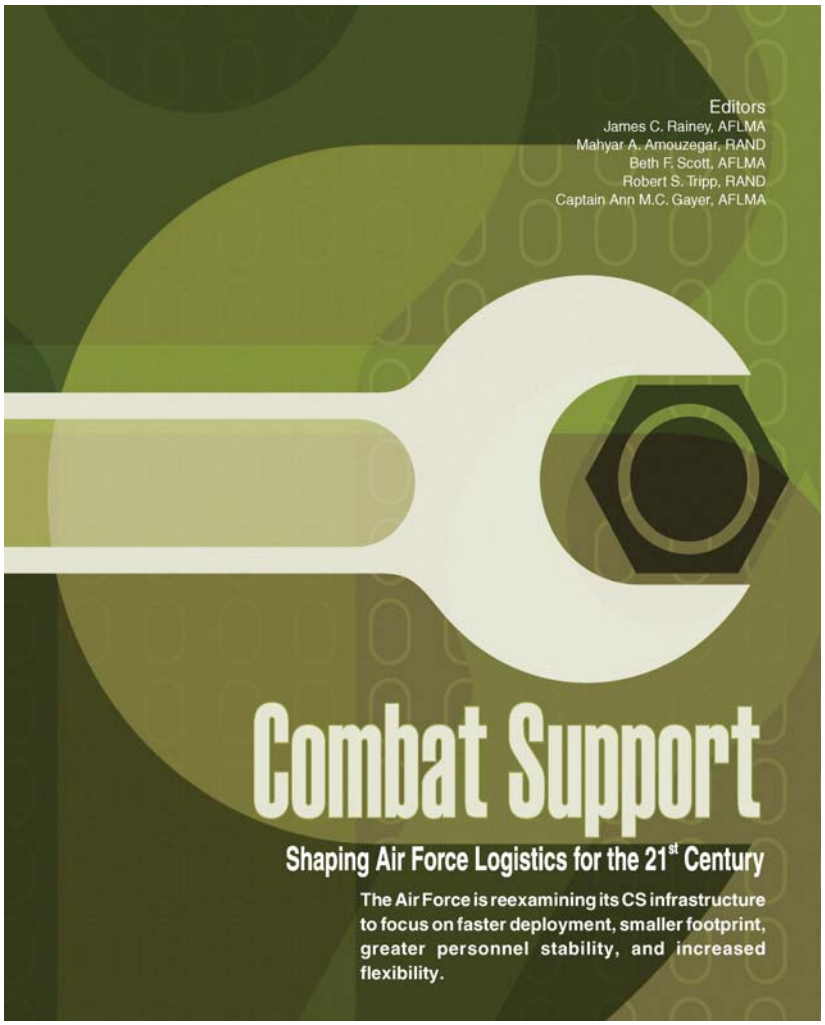
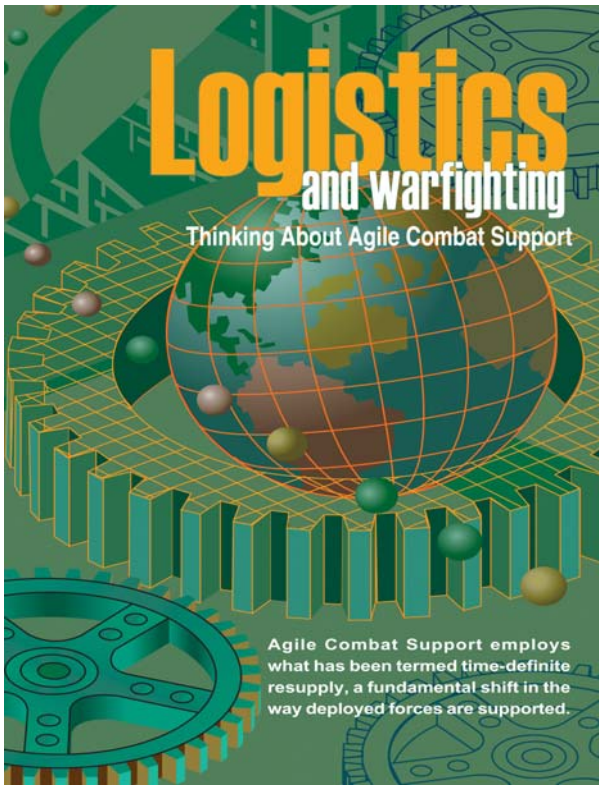
The research and thought that underpin our publications are of the highest quality. Many of the articles or essays presented were developed as part of our work with the Air War College, Air Command and Staff College, Air Mobility Warfare Center, RAND, and the Logistics Management Institute.



combat support

This publication communicates the essentials of the combat-support analyses completed by the Air Force Logistics Management Agency and RAND. The research was conducted to help the Air Force configure the agile combat support system in order to meet expeditionary airpower goals. These articles also illustrate how analysis can, when properly accomplished, influence Air Force policymaking. Additionally, the book can be used as a teaching document, illustrating the complexity of Air Force logistics systems and processes, as well as an archive of analytic methodology applied to military policy analysis. As a whole, the book can serve as a history of logistics during this 6-year period of extensive change, detailing where the Air Force has come from and why. Further, an examination of the entire collection can serve as an example of how to manage complex change and how to study large complex issues. Limited quantities.

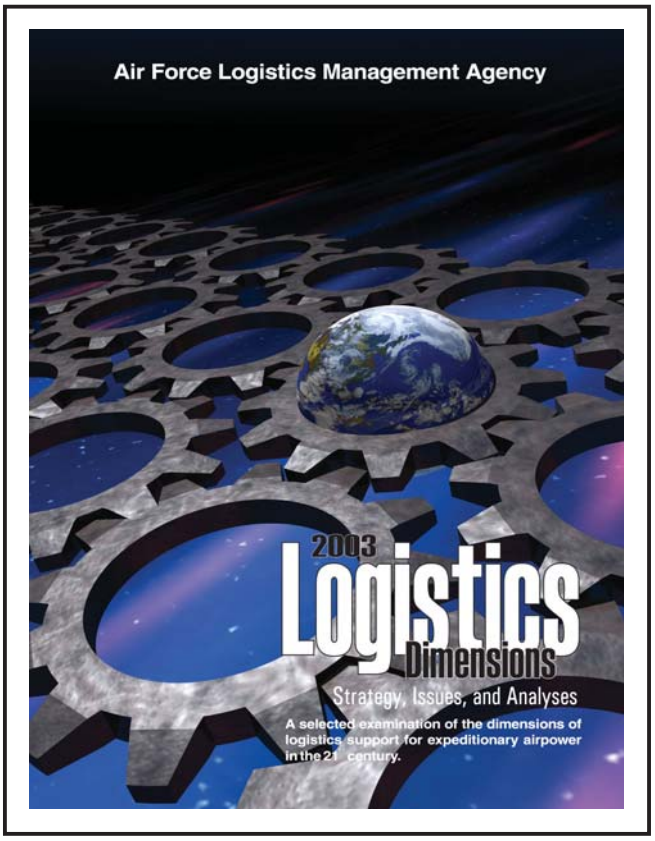


logistics and warfighting

This small book is a collection of essays, articles, and studies that lets the reader look broadly at many of the issues associated with agile combat support. The content was selected to both represent the diversity of the challenges faced and stimulate discussion about these challenges. Also included is a short history of transporting munitions. Limited quantities.

2003 logistics dimensions

Logistics Dimensions 2003 is a collection of seven essays, articles, and studies that lets the reader look broadly at many of the issues associated with the expeditionary air force of the 21st century. While small, *Logistics Dimensions 2003* addresses several of the major issues or challenges facing Air Force logistics. The content was selected to represent the diversity of the challenges faced and stimulate discussion about these challenges. Limited quantities.



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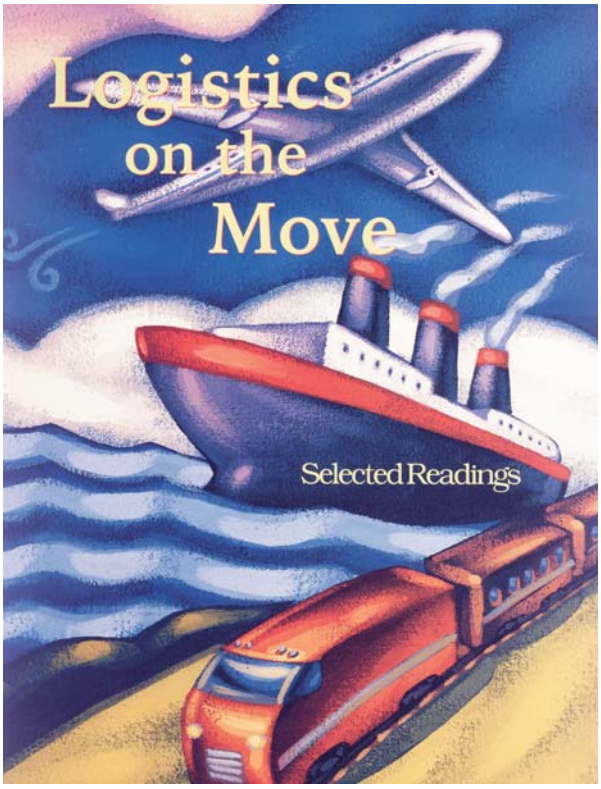
contractors on the battlefield

Contractors on the Battlefield is a collection of seven articles and essays that lets the reader look broadly at many of the initiatives involved with and the issues surrounding the increasing role of contractor support for the US military. It is by no means all encompassing. The very nature of the subject prevents this. These works were selected primarily to stimulate interest, thought, and action. In today's military environment, this thought-provoking monograph is a *must read*.

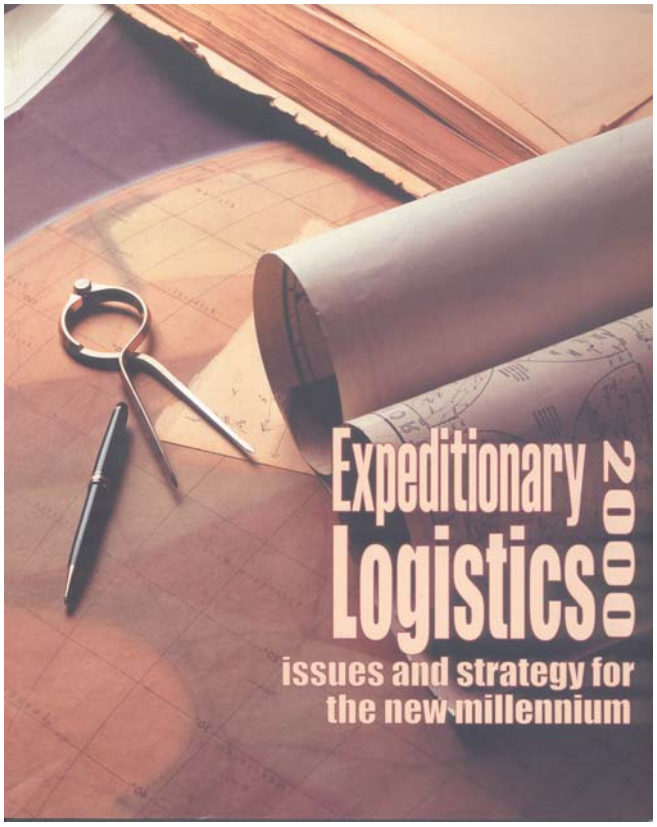


logistics on the move

Logistics on the Move is a collection of essays and articles that looks broadly at five areas of significant interest to logisticians—logistics thought, competitive sourcing and privatization, lessons from history, international logistics, and technology.

expeditionary logistics 2000

The force being molded today differs drastically from its predecessors. Rather than being reactive, airpower must now be proactive to meet the needs of a rapidly changing world. Today's definition of expeditionary airpower means a rapid response force that is light, lean, and tailored to mission needs. What are the challenges, opportunities, and initiatives that need examination? And perhaps more important, how do existing logistics concepts and principles need to change to support expeditionary airpower. *Expeditionary Logistics 2000: Issues and Strategy for the New Millennium* examines a number of these questions through a collection of selected readings.



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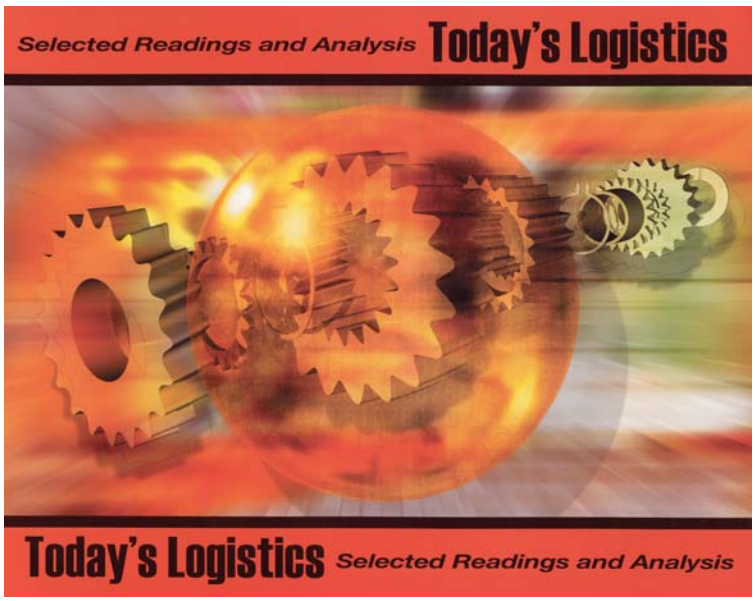
Two of our most popular handbooks or guidebooks—*Maintenance Metrics U.S. Air Force* and *Contingency Contracting: A Handbook for the Air Force CCO*—are also available in electronic format. As with our other books or monographs, they may be downloaded from the AFJL WWW site (http://www.aflma.hq.af.mil/lgj/Afjlhome.html) in portable document format and can be viewed online or downloaded.

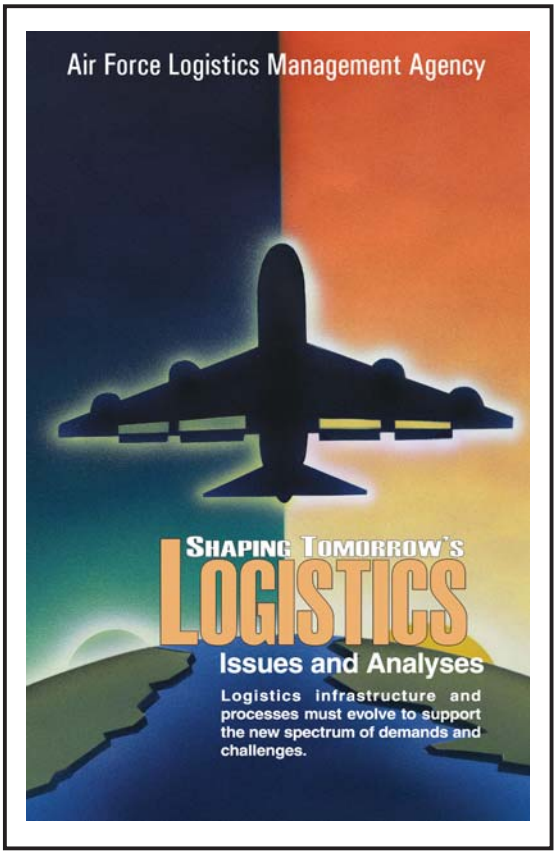


today's logistics

Today's Logistics is a collection of essays, articles, and studies that are very much about change, innovation, and finding ways to improve processes and products. The majority of the writings deal with improving specific facets of Air Force logistics: supply, transportation, maintenance, contracting, and prepositioning. However, other works have been included that focus on logistics thought, theory, crime, and history. Much of the material is based on work performed by the staff at the Air Force Logistics Management Agency.

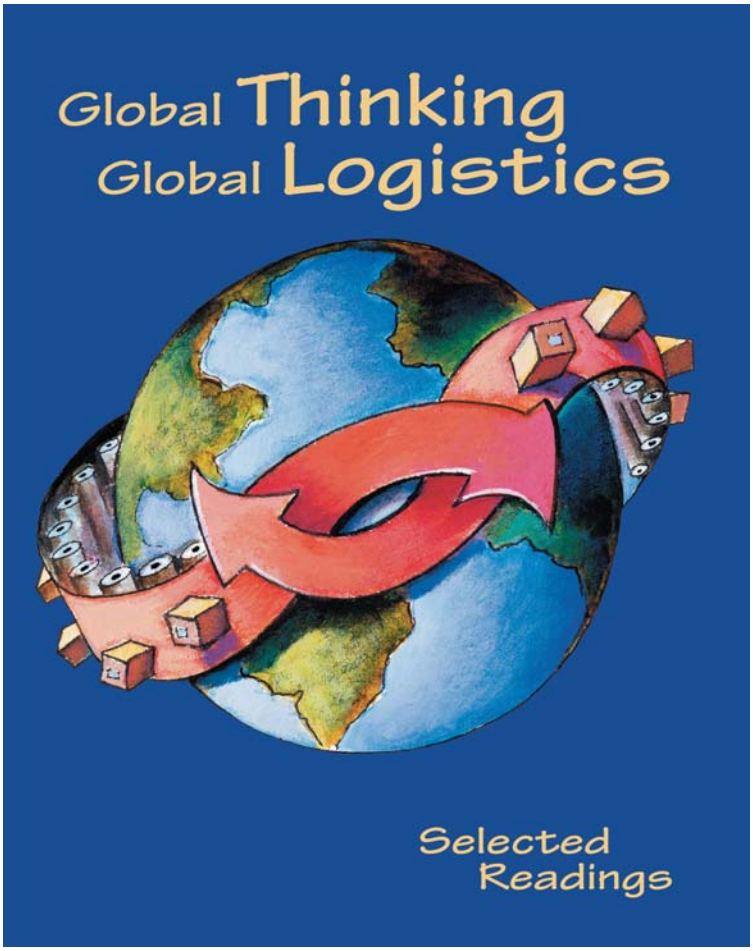
shaping tomorrow's logistics

Shaping Tomorrow's Logistics is a collection of 12 essays, articles, and studies that lets the reader examine a variety of research and thought that speaks to shaping and changing tomorrow's Air Force logistics. Included in the volume is the work of many authors with diverse interests and approaches. Much of the research discussed herein was conducted at the Air Force Logistics Management Agency.



global thinking, global logistics

Global Thinking, Global Logistics is a collection of articles and essays by many authors with diverse interests and approaches. However, it contains four distinct areas of interest or issues that face the military as we enter the 21st century: competitive sourcing and privatization, logistics support, logistics history and doctrine, and current challenges. The content was selected for two reasons: to represent the diversity of global logistics issues facing the military of the next century and stimulate thinking about these issues.



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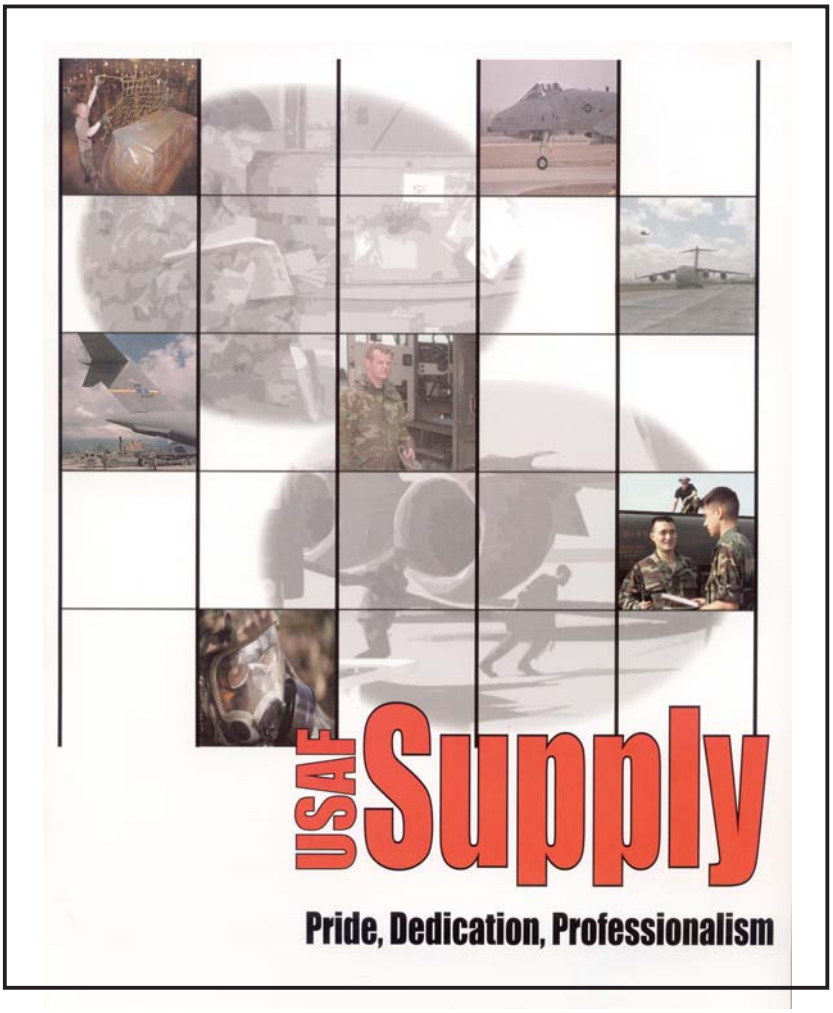
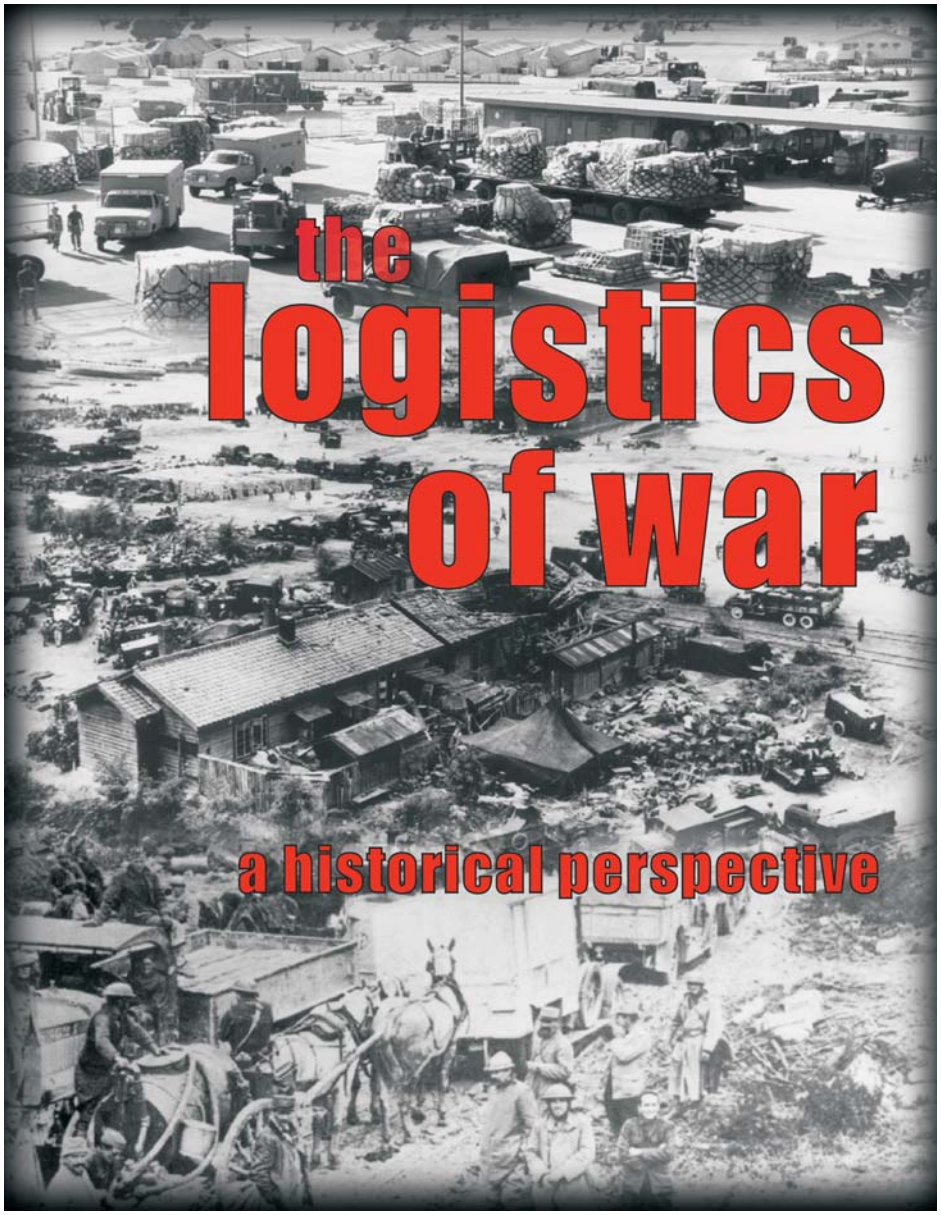


usaf supply

USAF Supply: Pride, Dedication, Professionalism highlights the past and future of Air Force supply. As a community, Air Force supply has much to be proud of. They were there when the Berlin Wall came down. They were there when the Cold War ended. And they are there today. As a community, they also have a lot to look forward to. New initiatives, new programs, and new challenges exist that will carry the supply-fuels family well into this century.



the logistics of war

The Logistics of War is a collection of three works that examines both broadly and specifically the history of US military logistics: *The Logistics of Waging War—American Logistics, 1774-1985—Emphasizing the Development of Airpower; The Logistics of Waging War—US Military Logistics 1982-1993—The End of Brute Force Logistics*; and the *History of US Military Logistics: 1935-1985, A Brief Review*. *The Logistics of Waging War—American Logistics, 1774-1985—Emphasizing the Development of Airpower* was originally published by the Air Force Logistics Management Agency as part of Project Warrior. While retaining its original character, this work has been extensively edited and reorganized, and two new sections were added: "The Logistics Constant Throughout the Ages" and "General Logistics Paradigm: A Study of the Logistics of Alexander, Napoleon, and Sherman." Readers of the old work will find this new version easy to navigate and a bit more user friendly. *The Logistics of Waging War—US Military Logistics 1982-1993—The End of Brute Force Logistics*, also originally published by the Air Force Logistics Management Agency, has likewise been extensively edited and updated. The final work is Jerome G. Peppers' seminal work on the history of US military logistics. Call and order your copy today.

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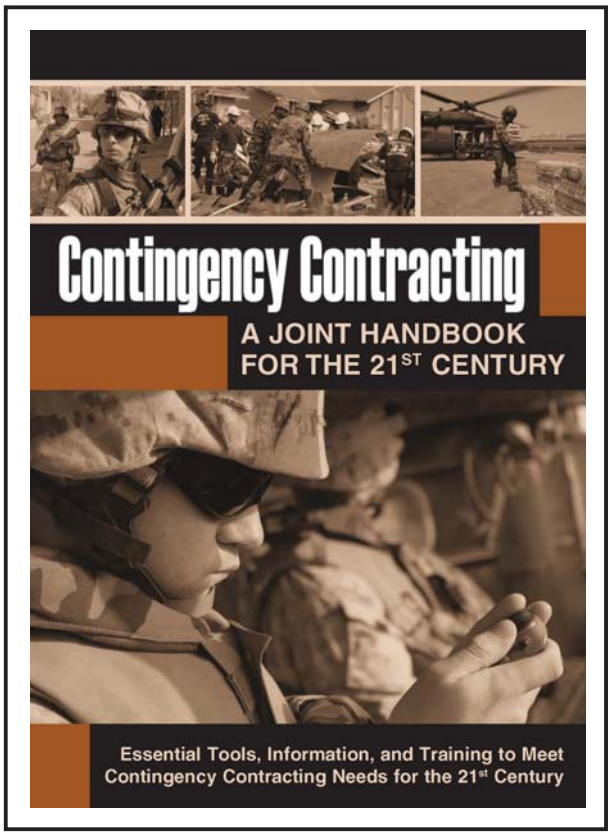

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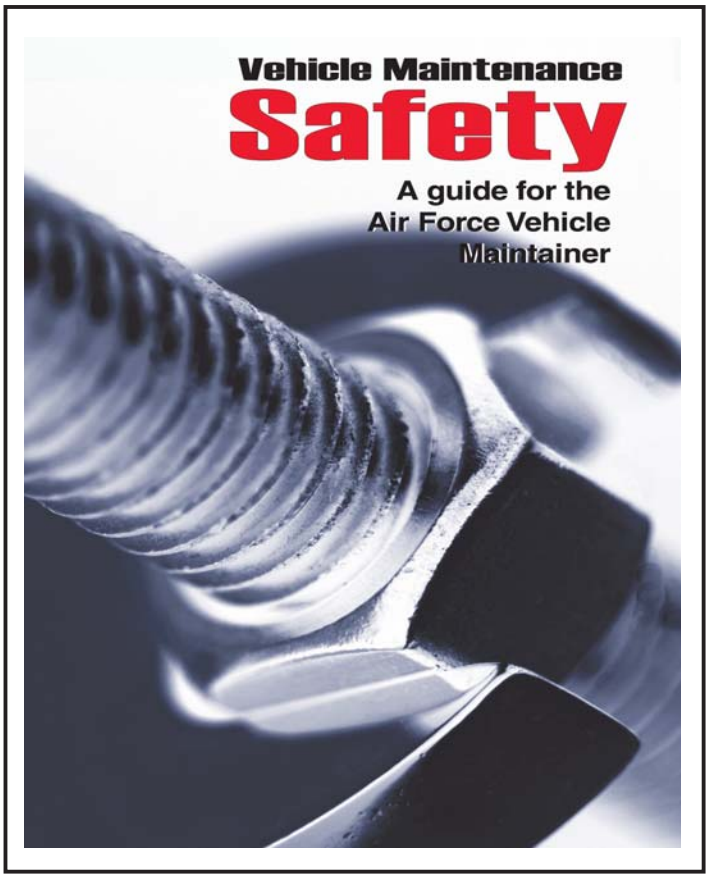
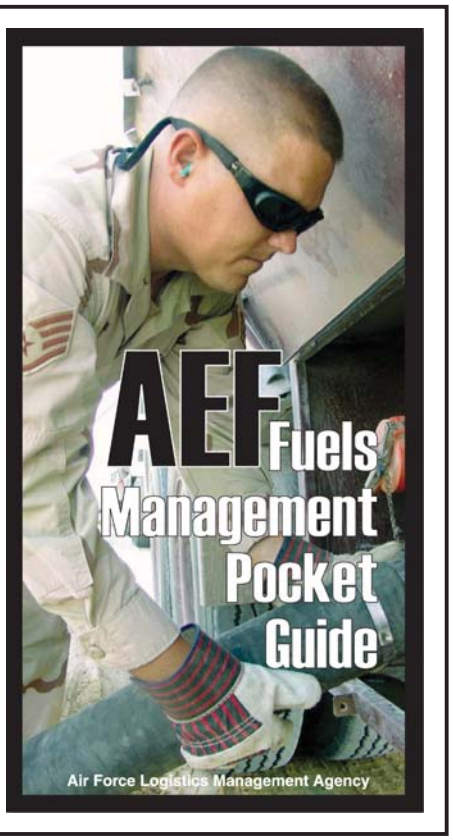
This pocket-sized handbook and its accompanying DVD provide the essential information, tools, and training for contracting officers to meet the challenges they will face, regardless of the mission or environment.

vehicle maintenance safety handbook

The *Vehicle Maintenance Safety Handbook* was produced in partnership with Air Staff and MAJCOM vehicle maintenance subject-matter experts for use in the Air Force 2T3 vehicle maintenance community. It's designed to improve safety awareness in the Air Force vehicle maintenance community. It provides practical information and draws on lessons learned from actual safety incidents. Limited quantities.





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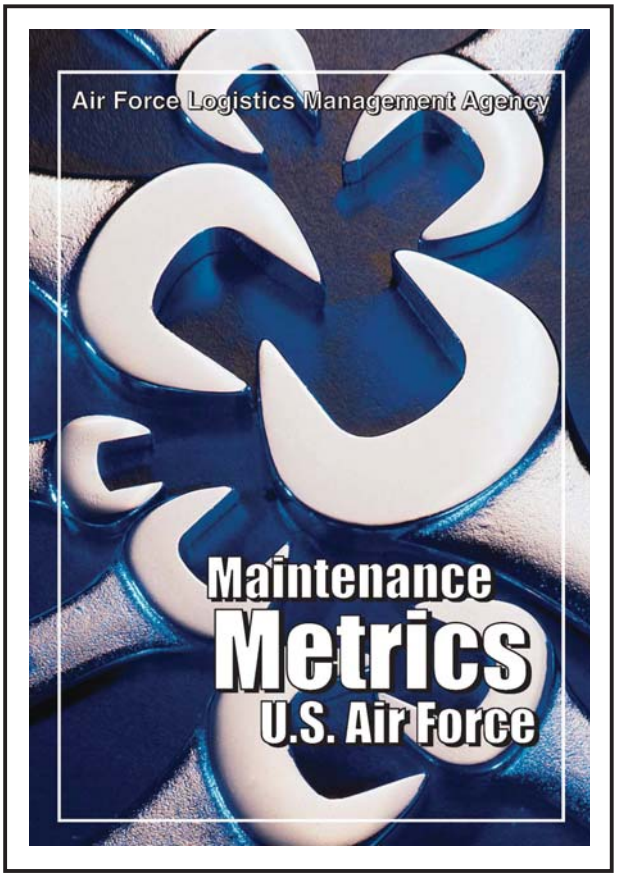

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