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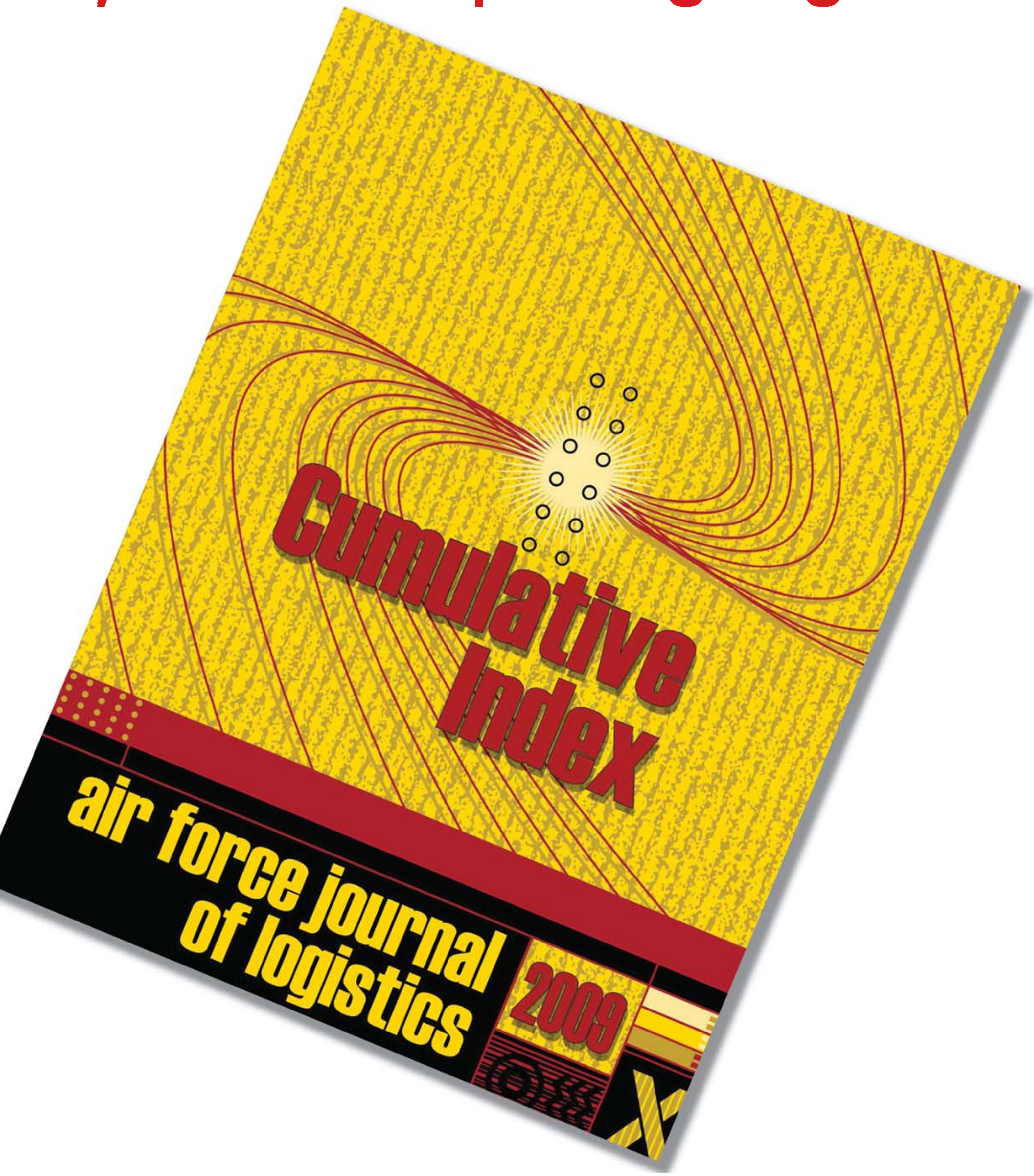

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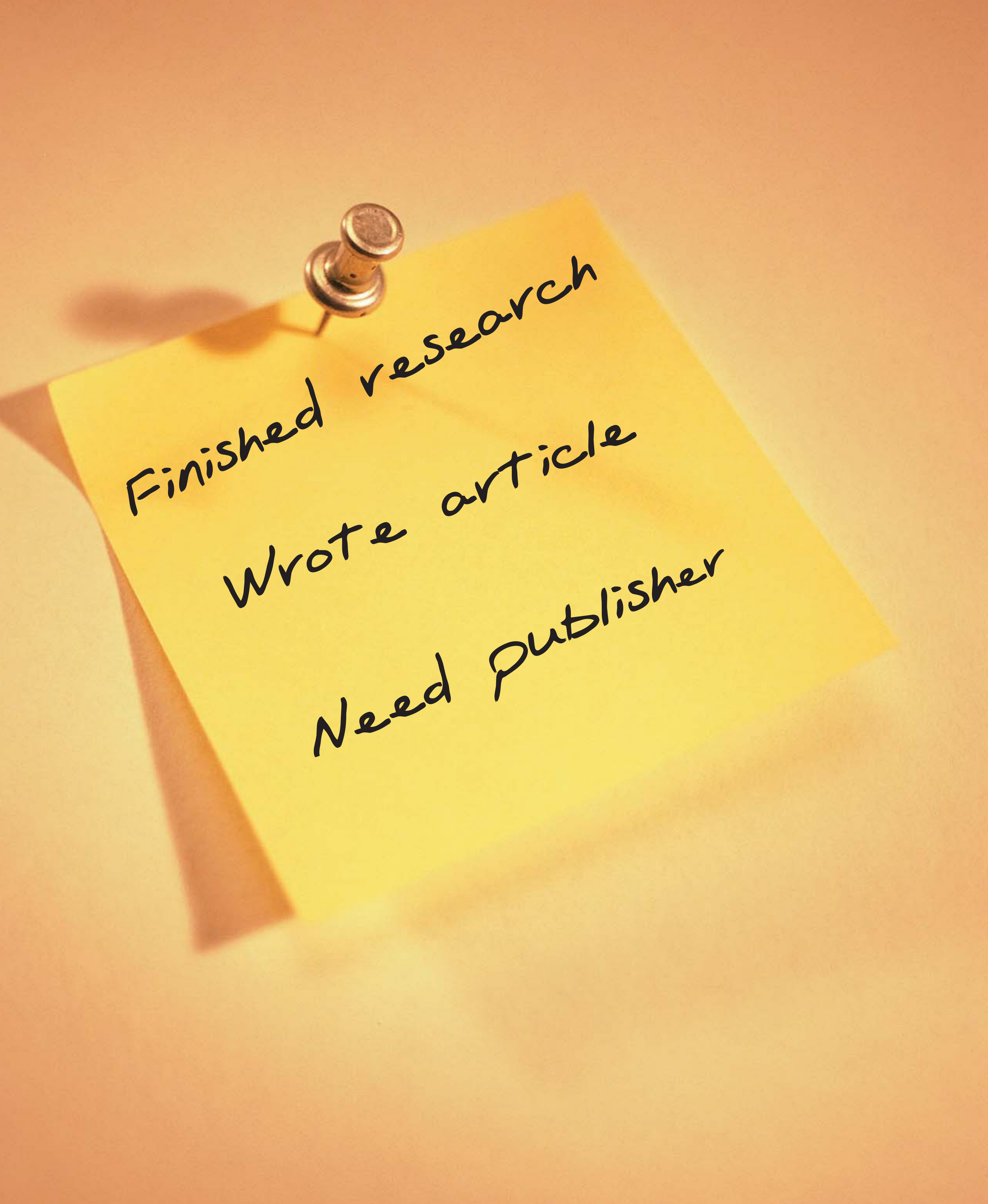
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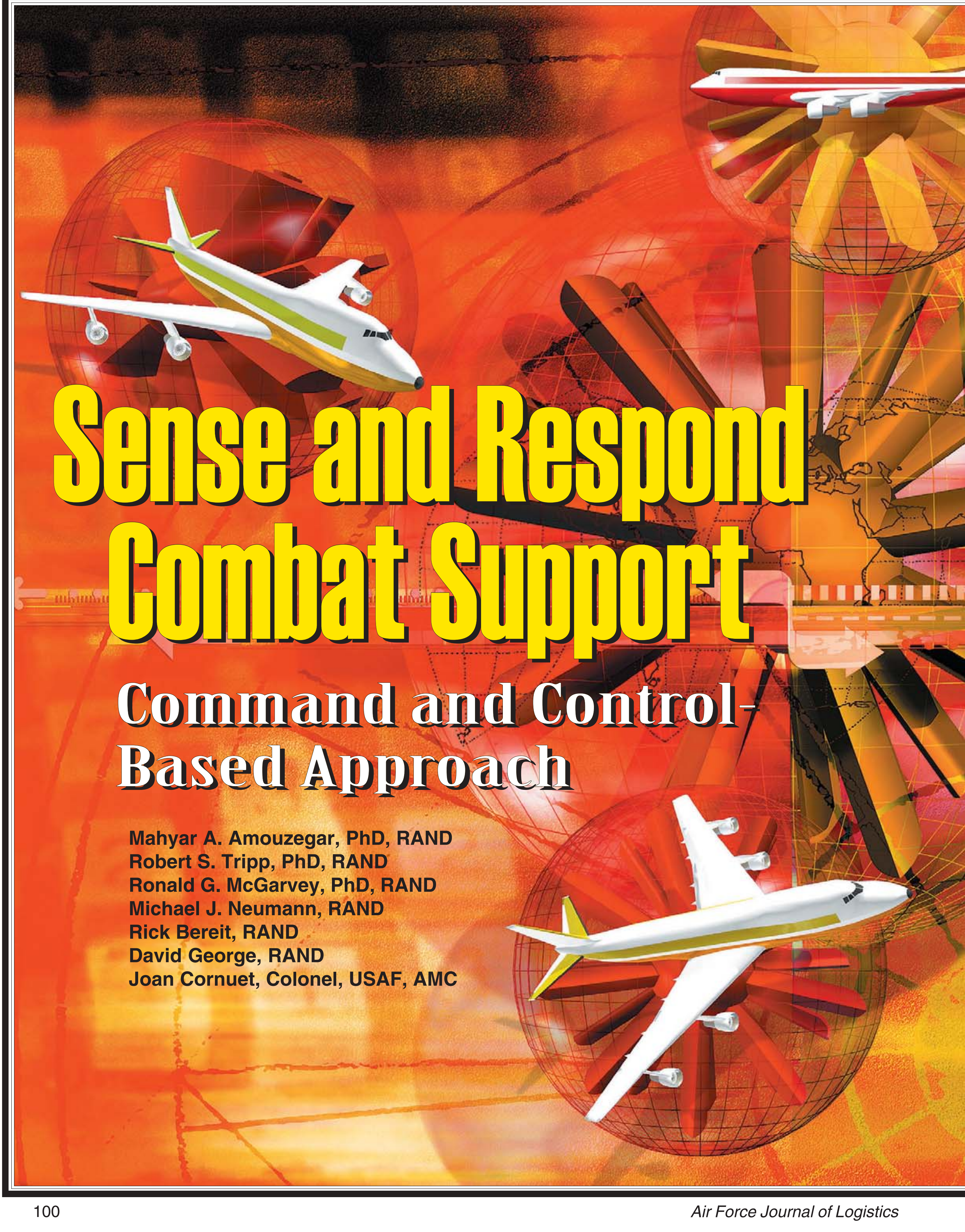

Sense and Respond Combat Support

Command and Control-Based Approach

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Selected Reading
Air Force Journal of Logistics

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.

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A Brief Survey of Sense and Respond Tools and Technology

The DoD Office of Force Transformation (OFT) developed the military sense and respond logistics concept, borrowing heavily from research in the commercial sector (which was in turn indebted to earlier military efforts, such as the observe, orient, decide, and act loop)[11] to describe an adaptive method for maintaining operational availability of units by managing their end-to-end support network. OFT addresses S&RL from a Joint force perspective and as an important component of DoD's focused logistics strategy.

OFT considered architectural development planning that includes the development of an information technology S&RL prototype. One of these architectural concepts is the Integrated Enterprise Domain Architecture, which has the objectives of integrating, accommodating, and employing concepts and components of logistics, operations, and intelligence architectures and of their command, control, communications, computers, intelligence, surveillance, and reconnaissance concepts.[12] Presently, Integrated Enterprise Domain Architecture is in a predevelopment stage, but plans are to eventually link it to other architectures or programs, including Joint Staff J4, Joint Forces Command, US Marine Corps, United States Transportation Command, and possibly certain organizations in the Navy and the Army. Among the in-work project linkages is the RAND-Air Force CSC2 Operational Architecture as the Air

Force vehicle for coordinating with concepts in S&RL.

Overall, the OFT program for S&RL is in a very early stage, but it has the potential to influence and effect near- to mid-term changes in some current programs using S&RL technologies. OFT suggests that elements of the concept can be employed in an evolutionary development in the very near term and could result in immediate operational gains.[13] OFT has also identified a number of technologies that are essential in an S&RL system, two of which were highlighted as especially important components: radio frequency identification and intelligent (adaptive) software agents.

However, before we discuss these components it is noteworthy to present some of the technical requirements that are essential in supporting sense and respond CS. Although there is great diversity amongst various approaches to sense and respond logistics implementation and its applications, a general theme is best stated by the IBM Sense and Respond Enterprise Team.[14] These criteria are in line with RAND's CSC2 concepts which the Air Force is in the process of implementing.[15] In general, technologies and innovation to support sense and respond (S&R) must have the following:

- The ability to detect, organize, and analyze pertinent information and sense critical business (force) conditions
- The filters for enterprise data to enable stable responses to disturbances in the business or military environment
- The intelligent response agents that analyze global value chain relationships and information and derive the optimal strategy for the best supply chain performance
- Predictive modeling at multiple levels: strategic, tactical, and operational
- Agent coordination mechanisms at multiple levels: strategic, tactical, and operational
- The ability to learn by comparing previously predicted trends with recorded data and information to improve future responses
- A software infrastructure to integrate heterogeneous and collaborative agents implementing critical business policies and making operational decisions

This concept can be contrasted with the OFT perspective. OFT, within its All Views Architecture, lists specific systems architecture components for S&RL, including the following capabilities:[16]

- Passive and active tagging, instruments, and sensors that provide location status, diagnoses, prognoses, and other information relative to operations space entities, especially for conditions and behavior that affect force capabilities management, logistics, and sustainment.
- Intelligent software agents that represent operations space entities, conditions, and behaviors, provide a focus for control of action or behavior, or act as monitors.
- S&RL knowledge bases oriented toward force capabilities management, logistics, and sustainment.
- S&RL reference data, again focused on force capabilities, assets, and resources related to force capabilities management, logistics, and sustainment.
- S&RL rule sets, which govern the operations and organization of S&RL functions, activities, and transactions.
- S&RL cognitive decision support tools uniquely supporting force capabilities management, logistics, and sustainment.
- Unique S&RL processes, applications, portals, and interfaces not provided either by Distributed Adaptive Operations Command and Control or the Network-Centric Operations and Warfare infrastructure.

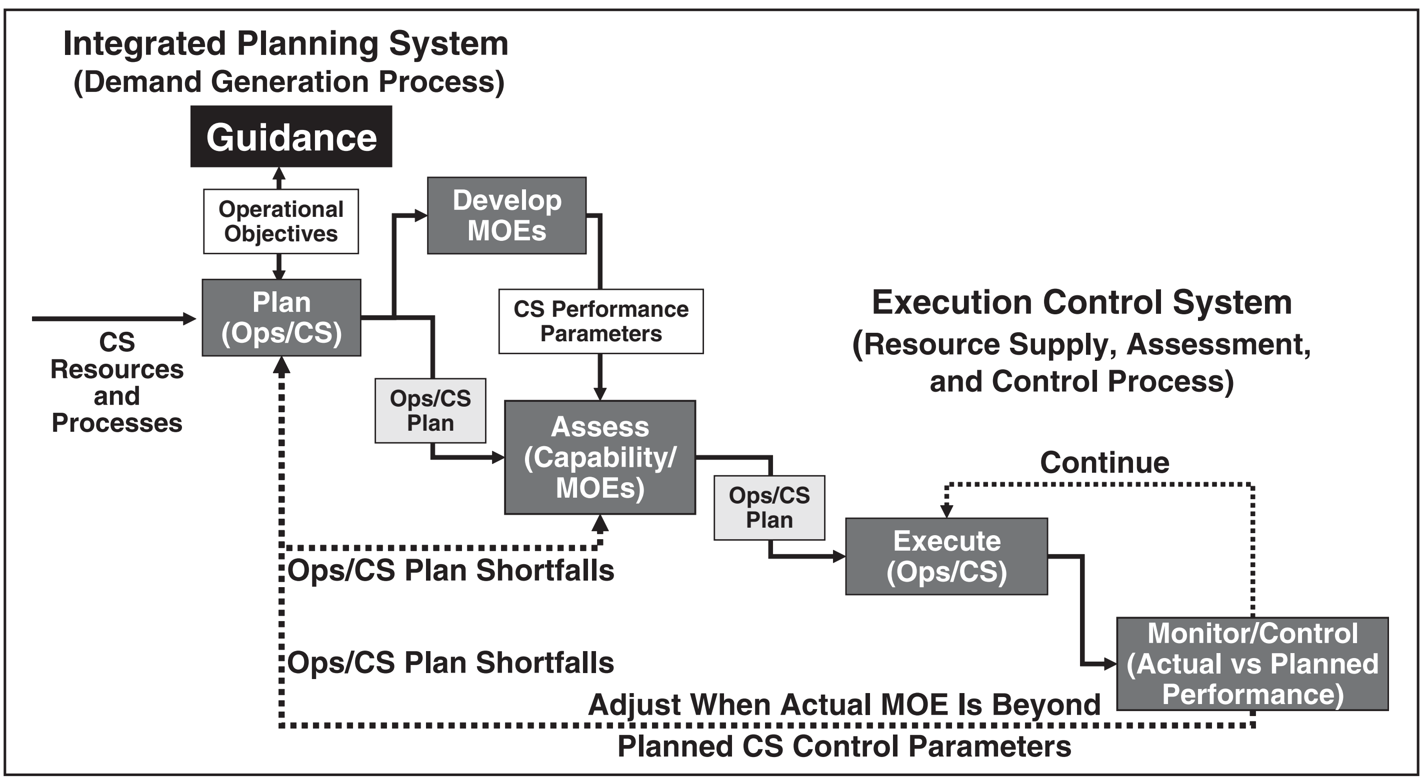

Figure 1. Feedback Loop Process

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.

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.

Although individual automated software agents are already employed commercially for particular tasks, intelligent multi-agent systems are still in early development. Consequently, ABMs have historically 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.

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

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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

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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

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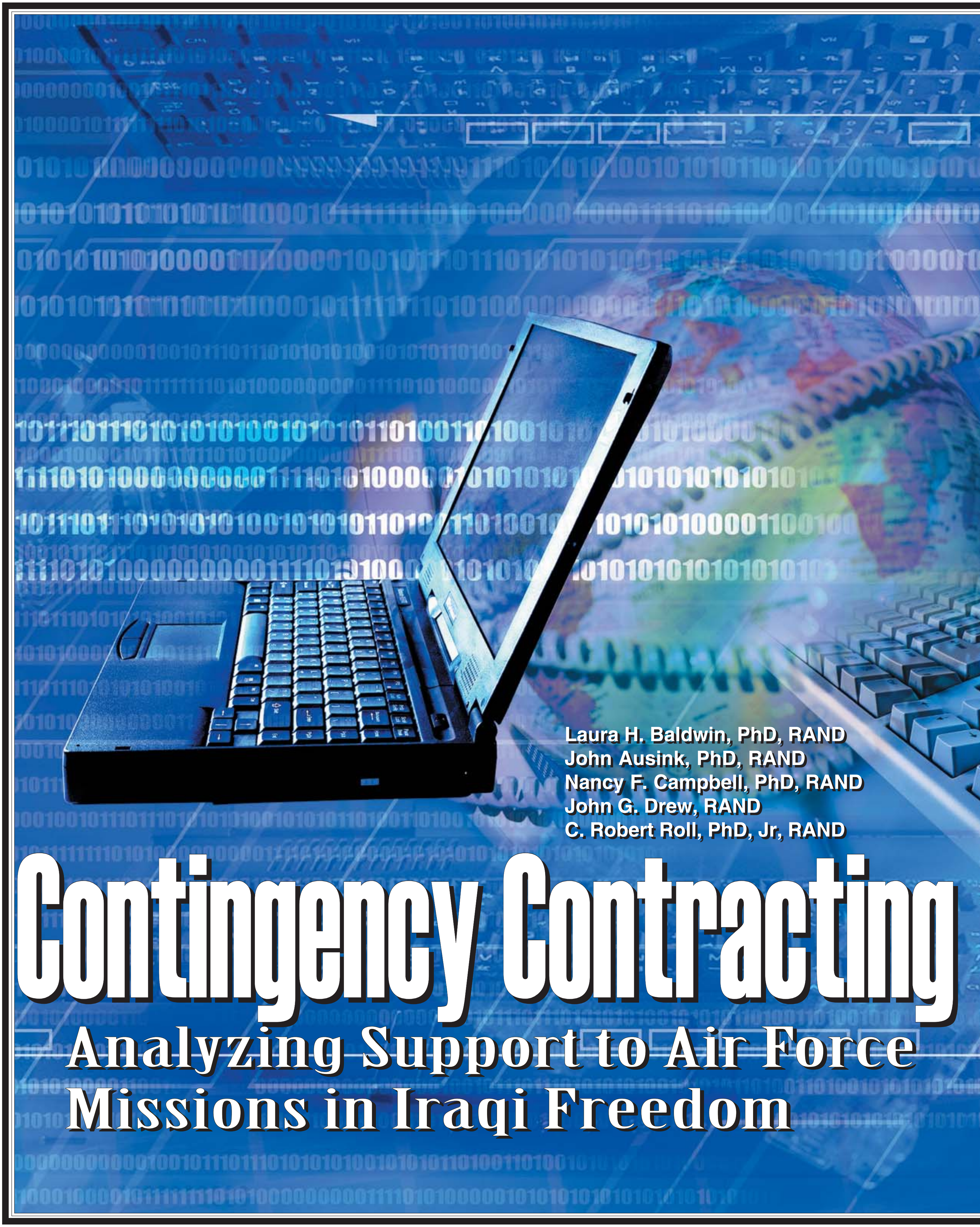
Group Captain Peter J. Dye, RAF



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Contingency Contracting

Analyzing Support to Air Force Missions in Iraqi Freedom

Selected Reading
Air Force Journal of Logistics

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]

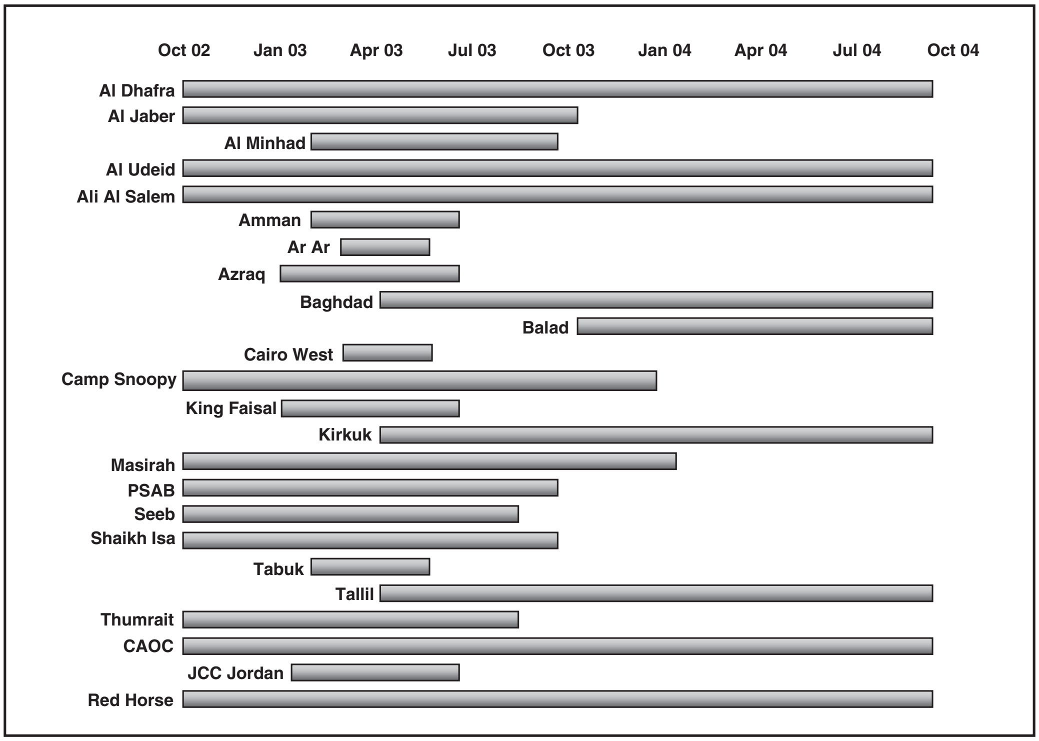

Figure 1. Time Lines for Purchasing Activity, by Purchasing Organization

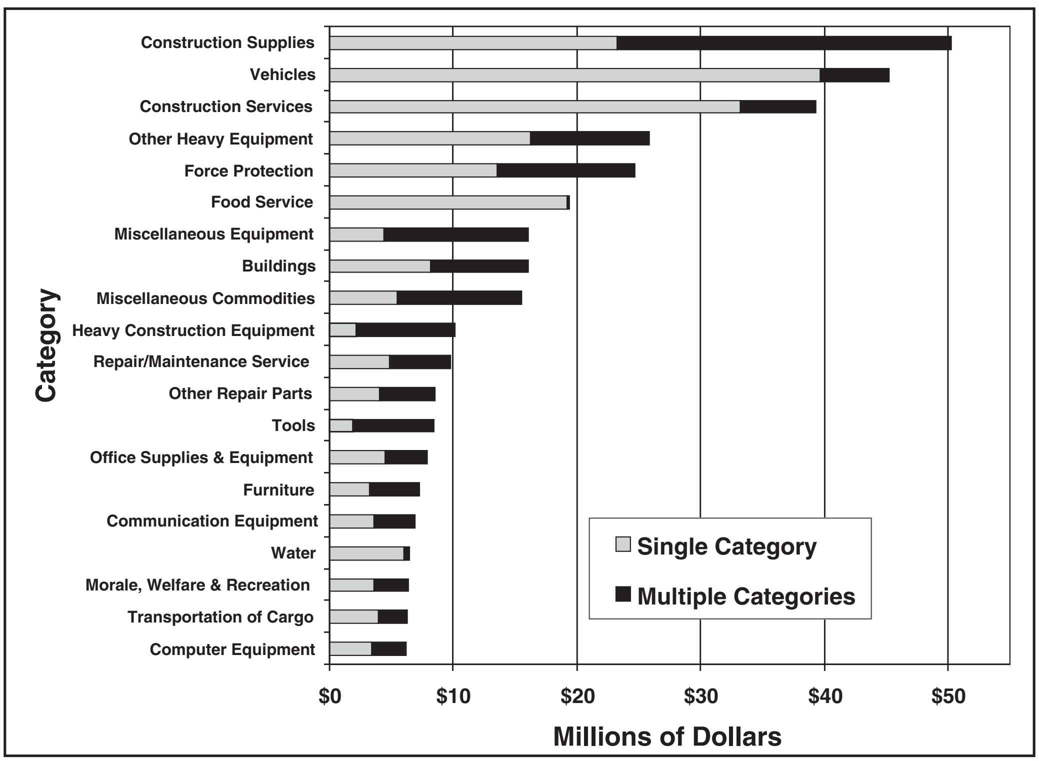

Figure 2. Obligations for the Top 20 Categories, FY03 and FY04

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.

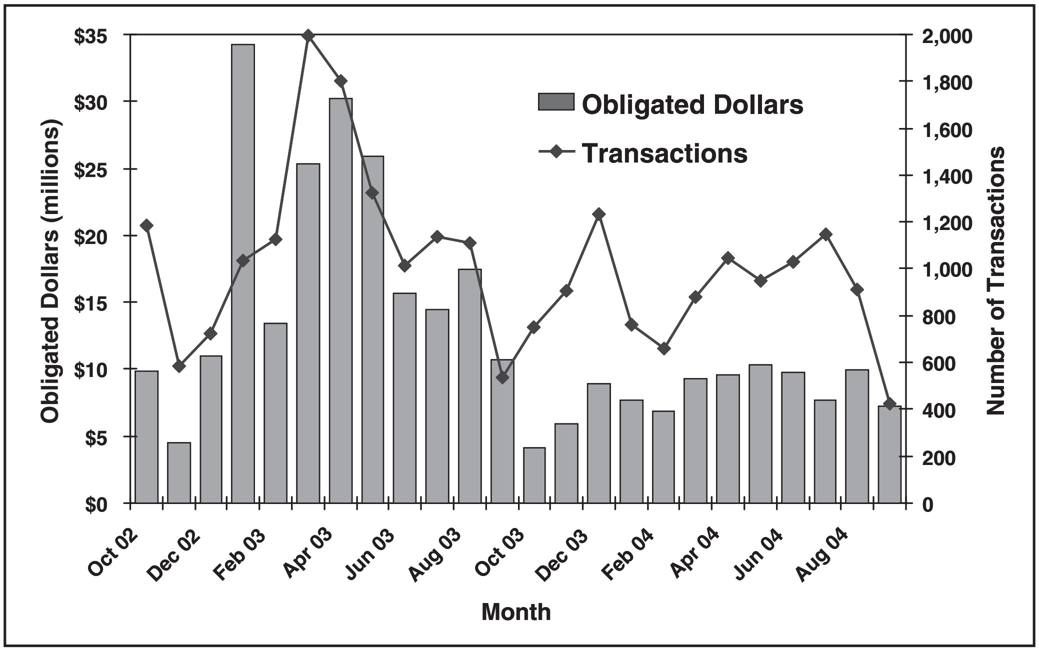

Figure 3. Obligations and Transactions by Month, FY03 and FY04.

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.

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.

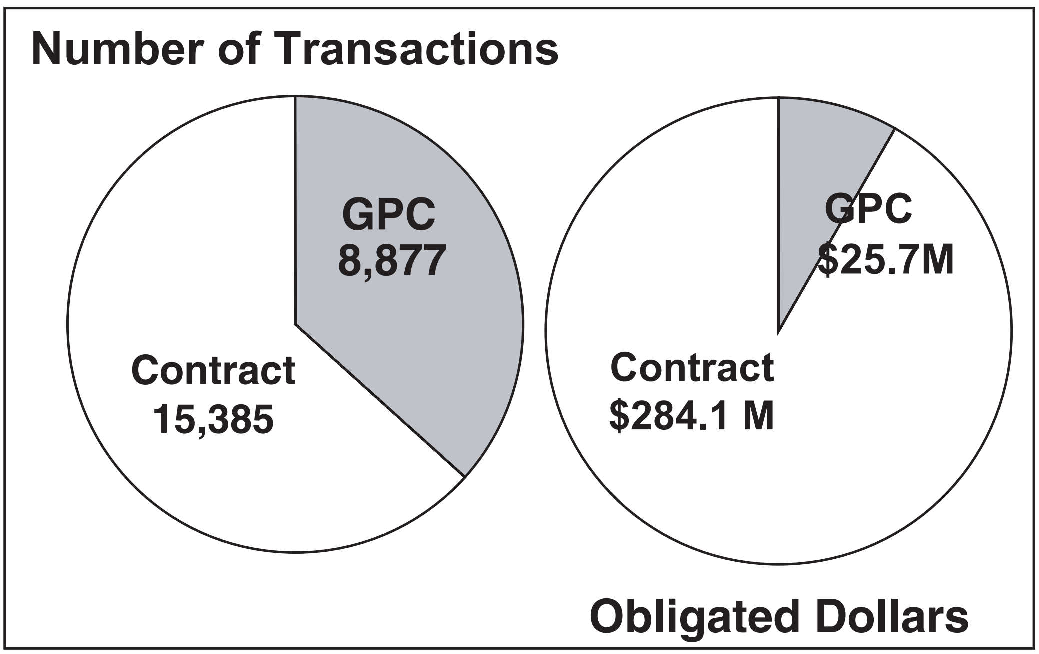

Figure 4. GPC versus Contract Purchases in FY03 and FY04.

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.

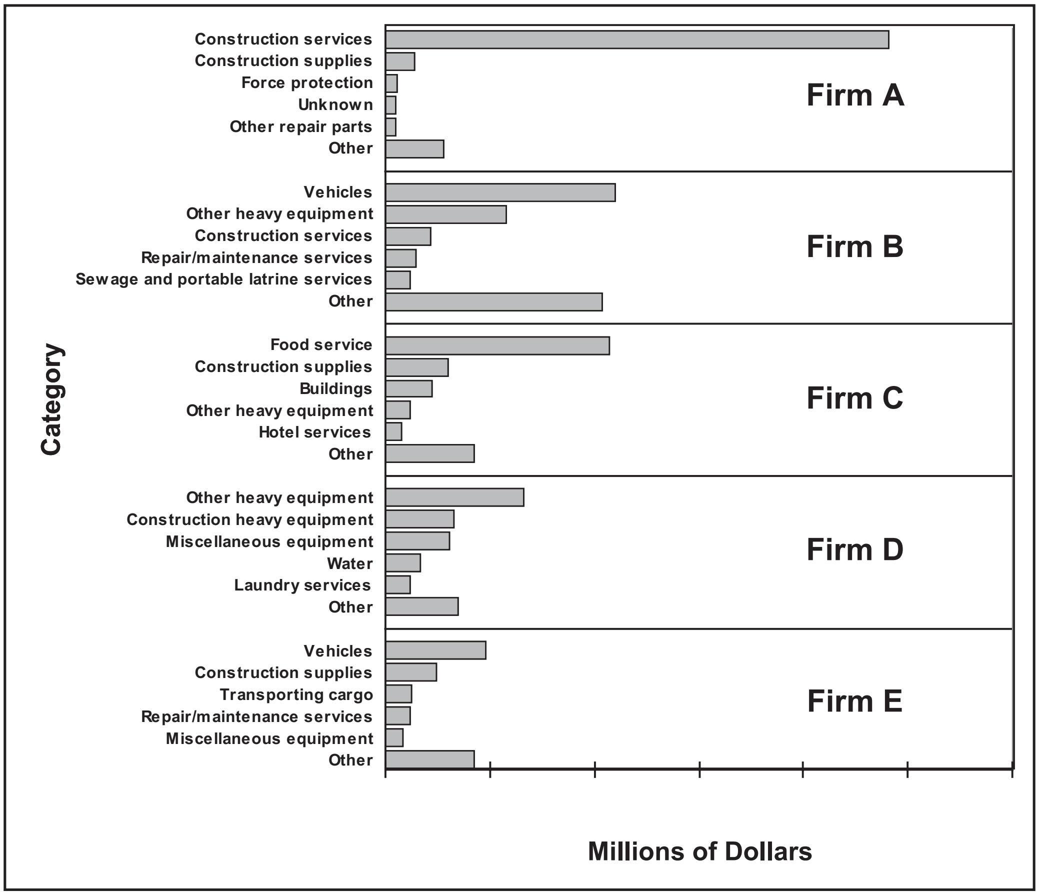

Figure 5. Top Five Purchase Categories for the Top Five Suppliers

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.

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***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.*

Selected Reading
Air Force Journal of Logistics

Beyond Aut

Aircraft

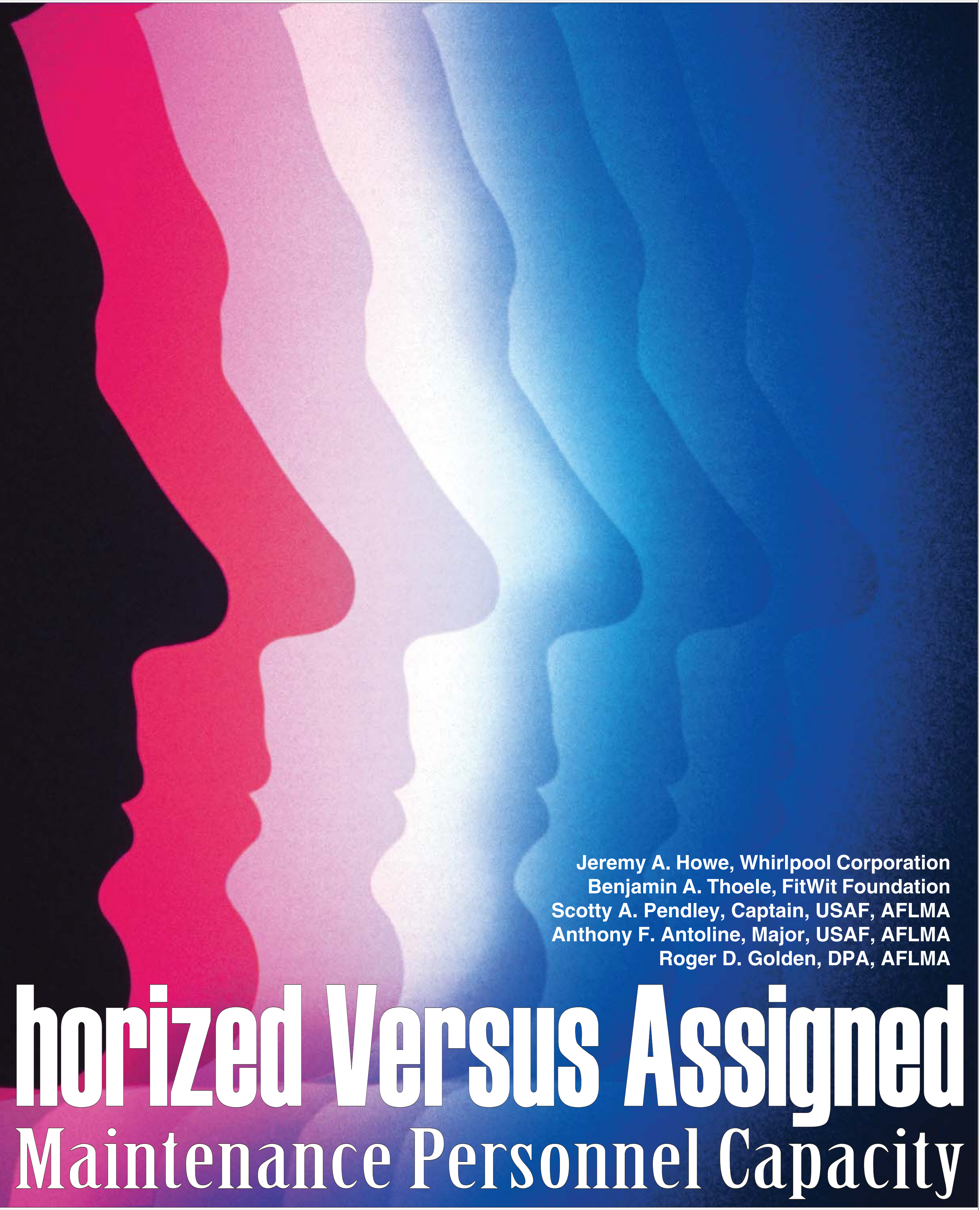
Introduction

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
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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

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

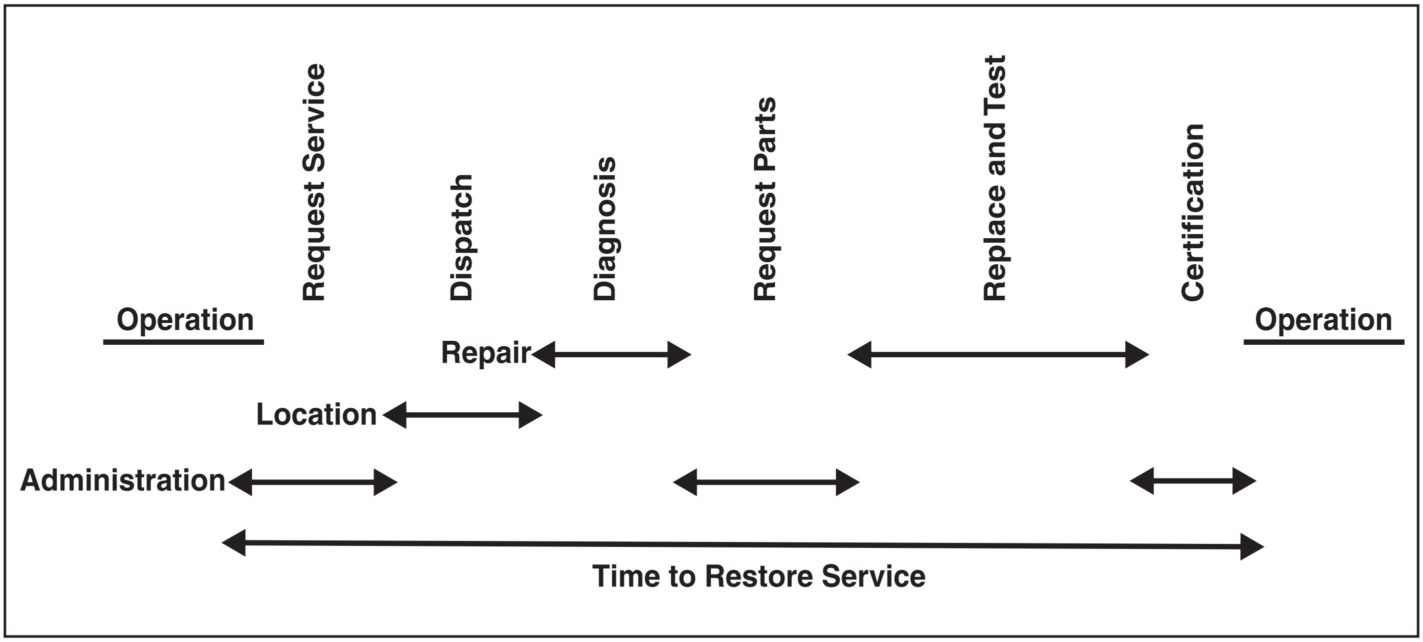


Figure 1. Time to Restore Service Process Model[10]

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.

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

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

Equation 1. Net Effective Personnel

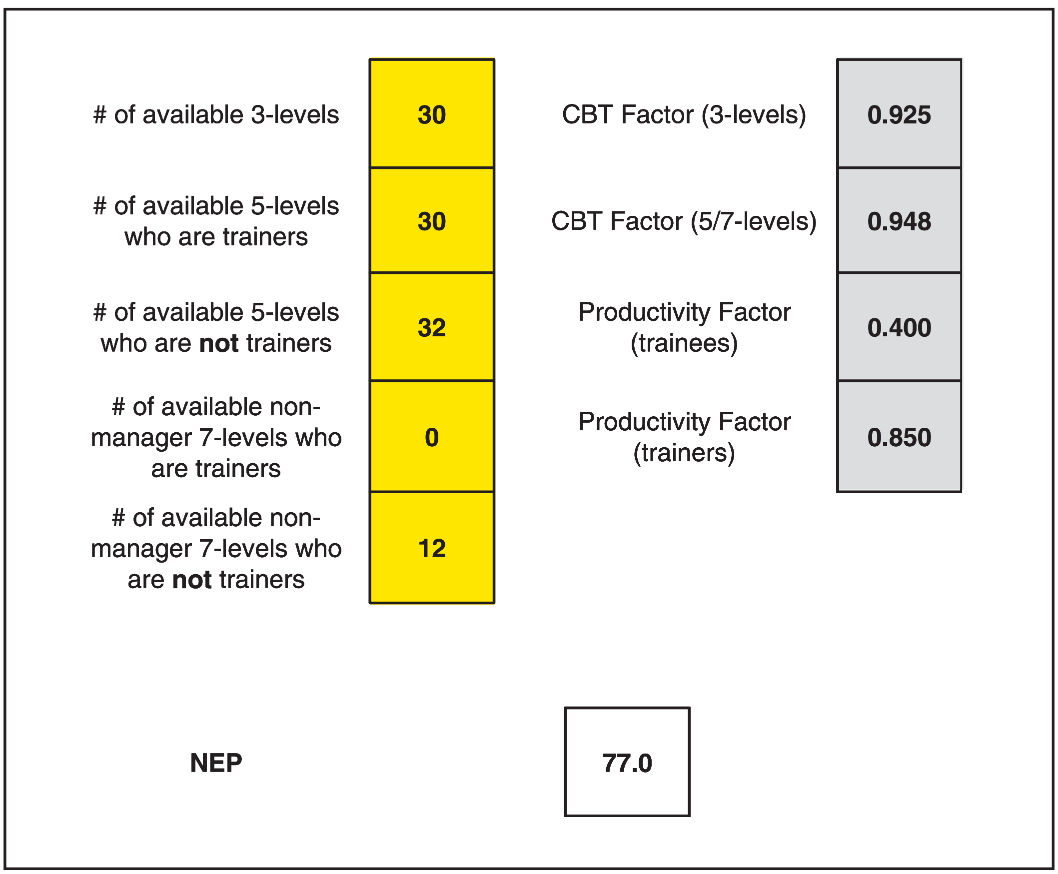
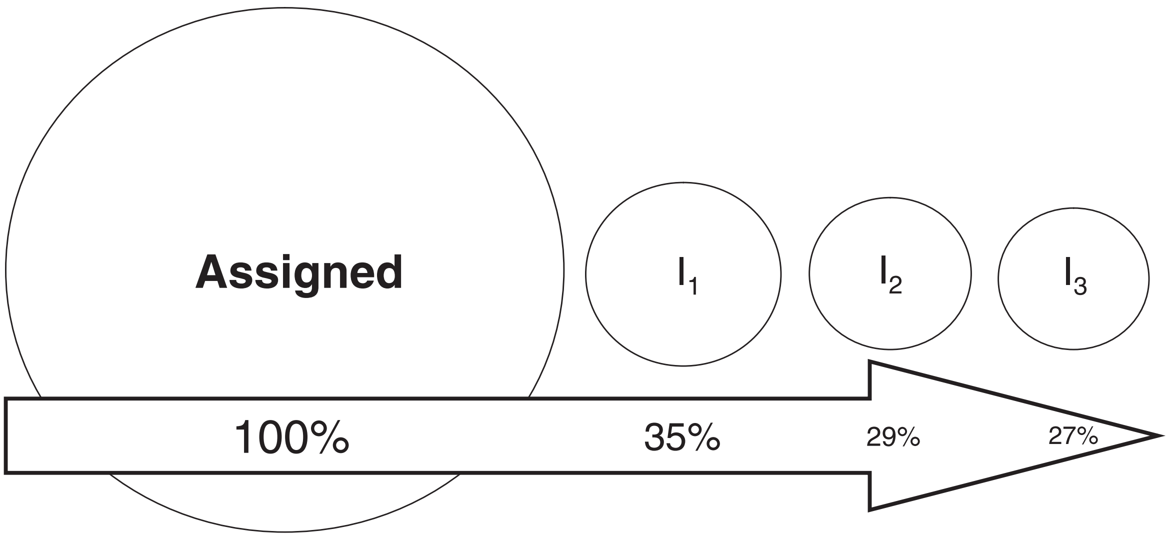


Figure 3. Example NEP Calculation



- Iteration 1 (I_1) : Availability
  - $A_{75NT} + A_{75T} + A_3$
- Iteration 2 (I_2) : Availability and Productivity
  - $A_{75NT} + P_tA_{75T} + P_eA_3$
- Iteration 3 (I_3) : Availability, Productivity, CBT and Ancillary Training
  - $T_{75}(A_{75NT} + P_tA_{75T}) + T_3(P_eA_3)$

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.
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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.

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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]

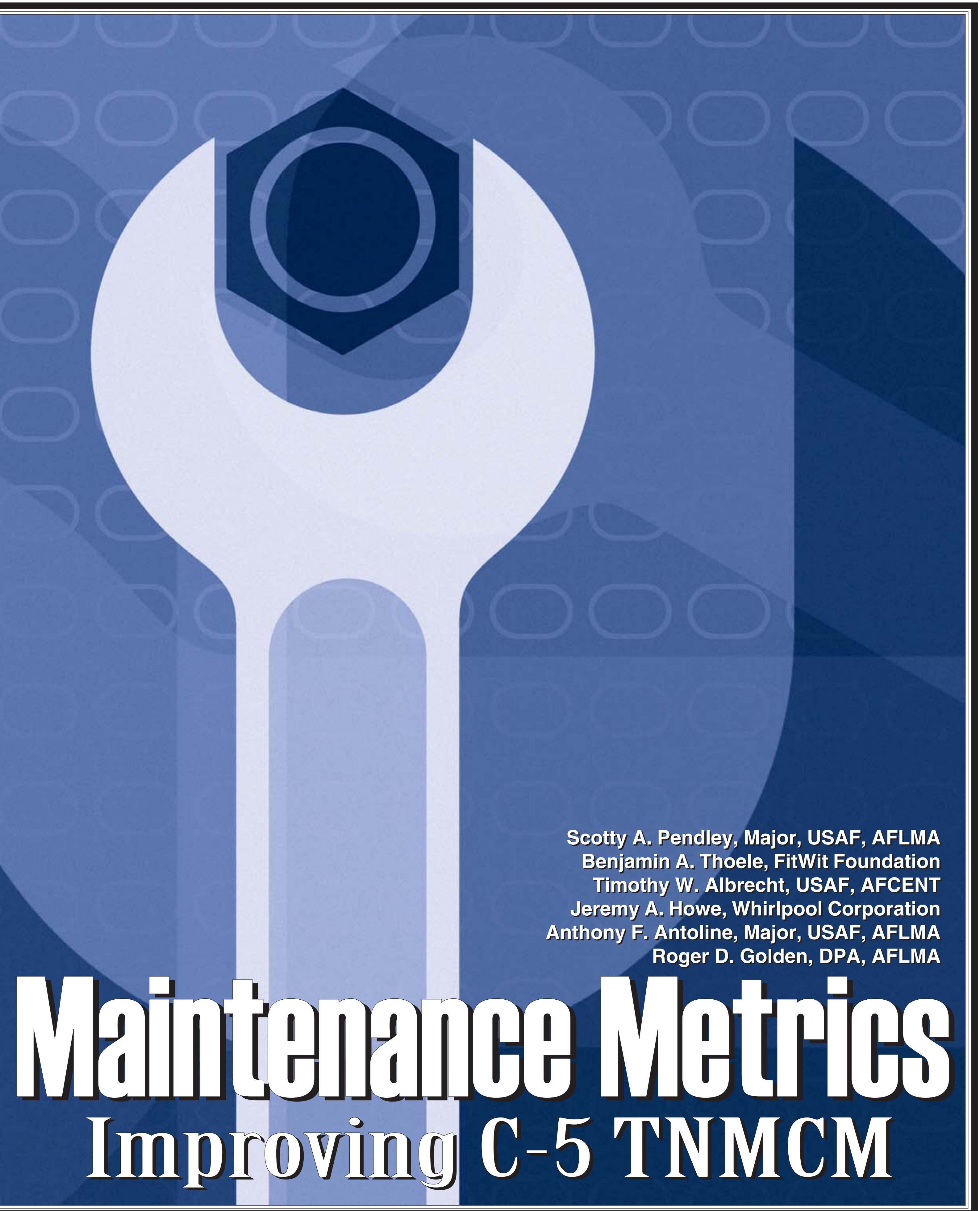
Dr Michael Hammer, a recognized leader in the field of process reengineering, also notes four principles of measurement.

- 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



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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:

- $|\rho| \leq 0.20$ implies a very weak correlation
- $0.20 < |\rho| \leq 0.50$ implies a weak correlation
- $0.50 < |\rho| \leq 0.80$ implies a moderate correlation
- $0.80 < |\rho| \leq 1.0$ 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

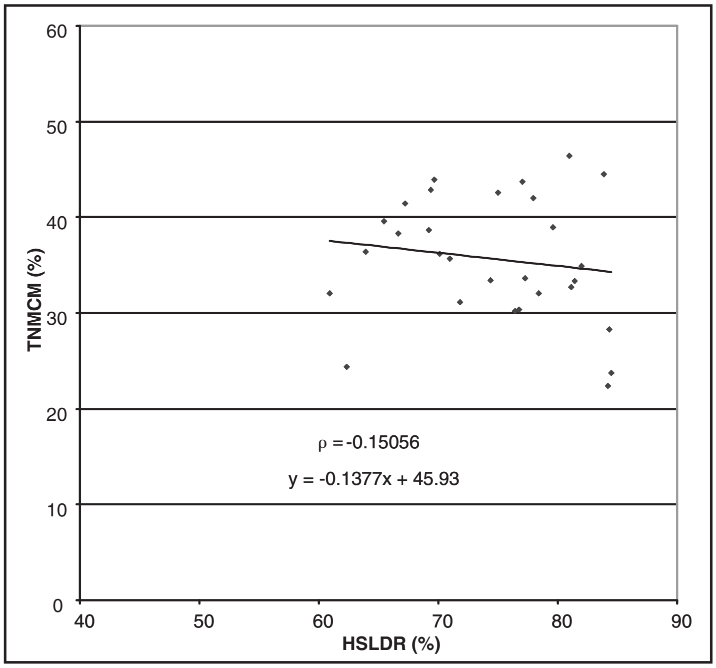

Figure 1. HSLDR and TNMCM Rates Scatter Plot for 436 MXG August 2004 to December 2006

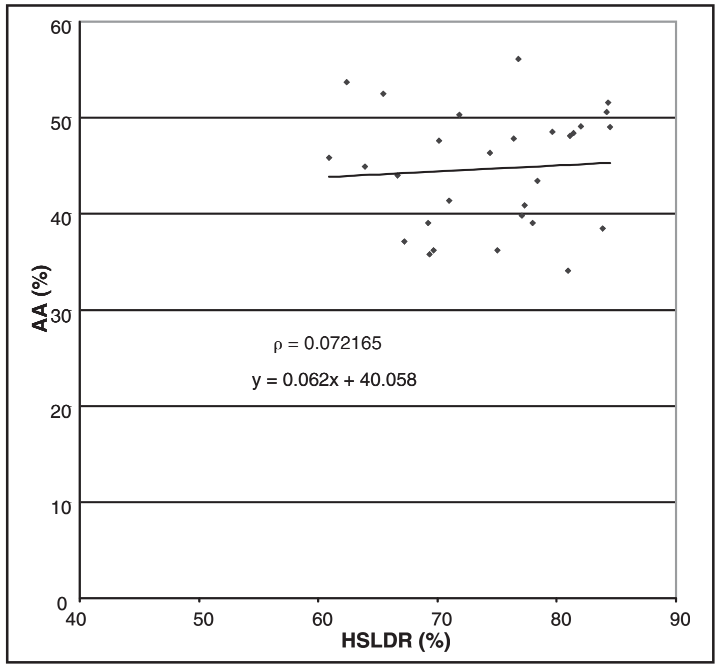

Figure 2. HSLDR and AA Rates Scatter Plot for 436 MXG August 2004 to December 2006

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.

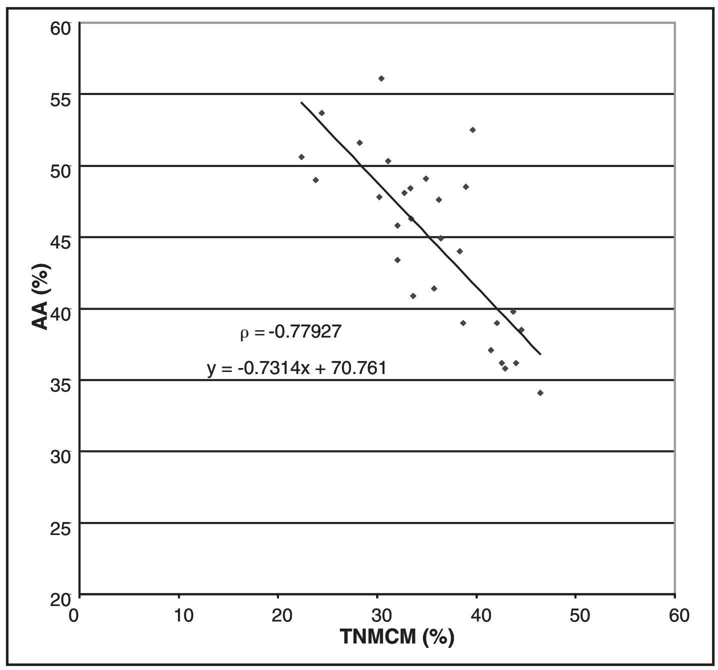

Figure 3. TNMCM and AA Rates Scatter Plot for 436th MXG August 2004 to December 2006

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

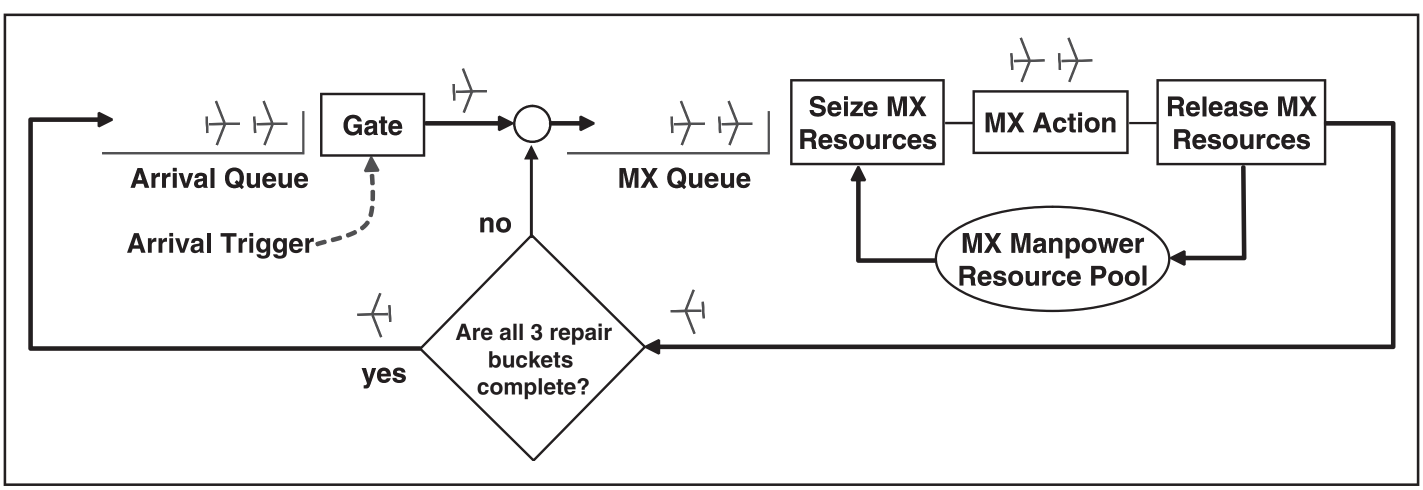

Figure 4. Maintenance Process as Modeled in the C-5 MXP Simulation

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/.

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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

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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

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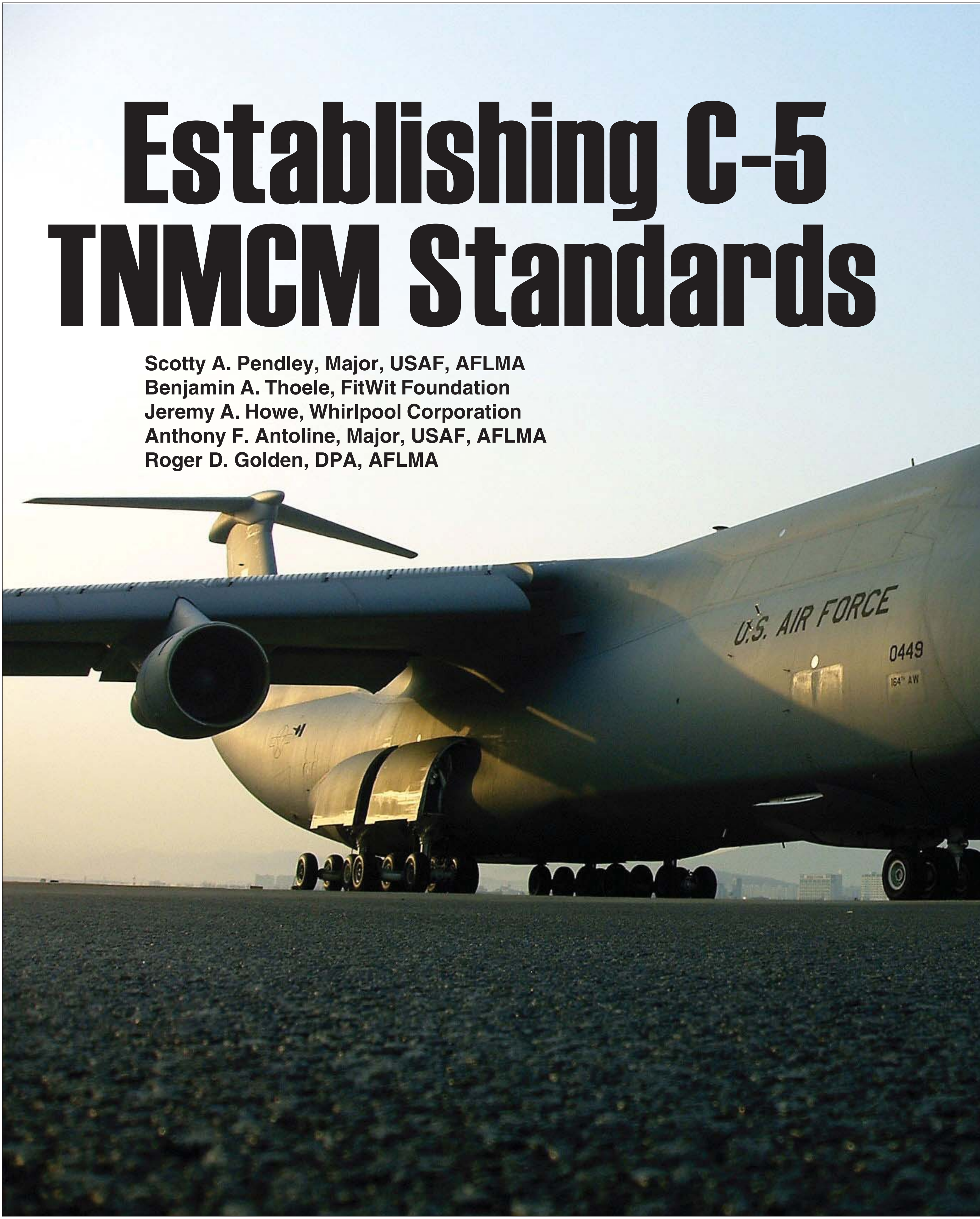

Selected Reading
Air Force Journal of Logistics

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]

$$TNMCS\ (\%) = \frac{\text{NMCS Hrs} + \text{NMCB Hrs}}{\text{Possessed Hours}} \times 100\%$$

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.

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

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]

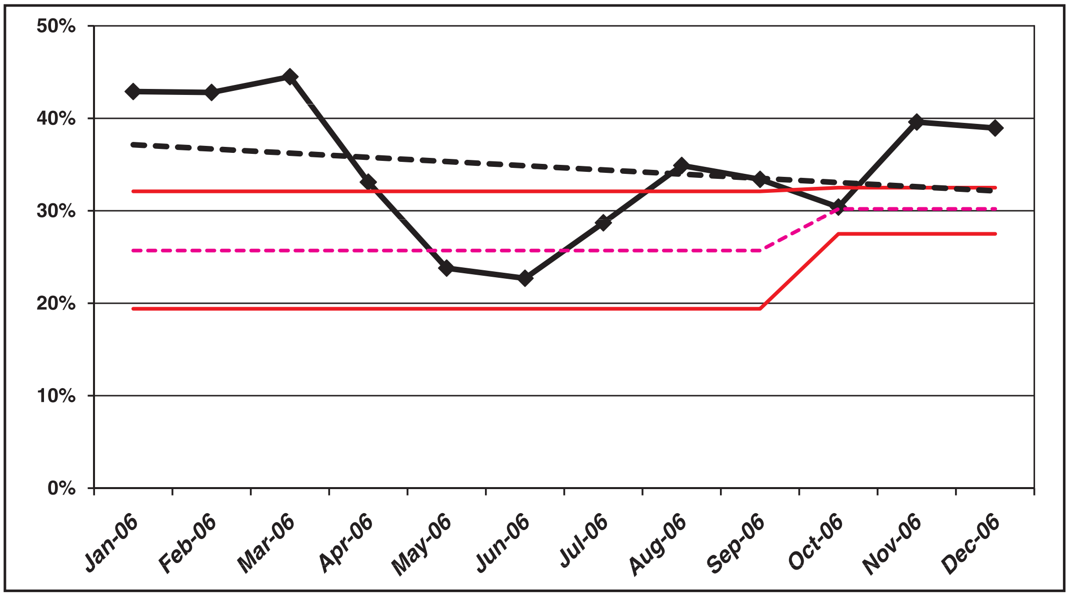

Figure 1. Example of TNMCM Control Chart, Dover AFB 2006[50]

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

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Selected Reading

Air Force Journal of Logistics

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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 $Time_{now}$

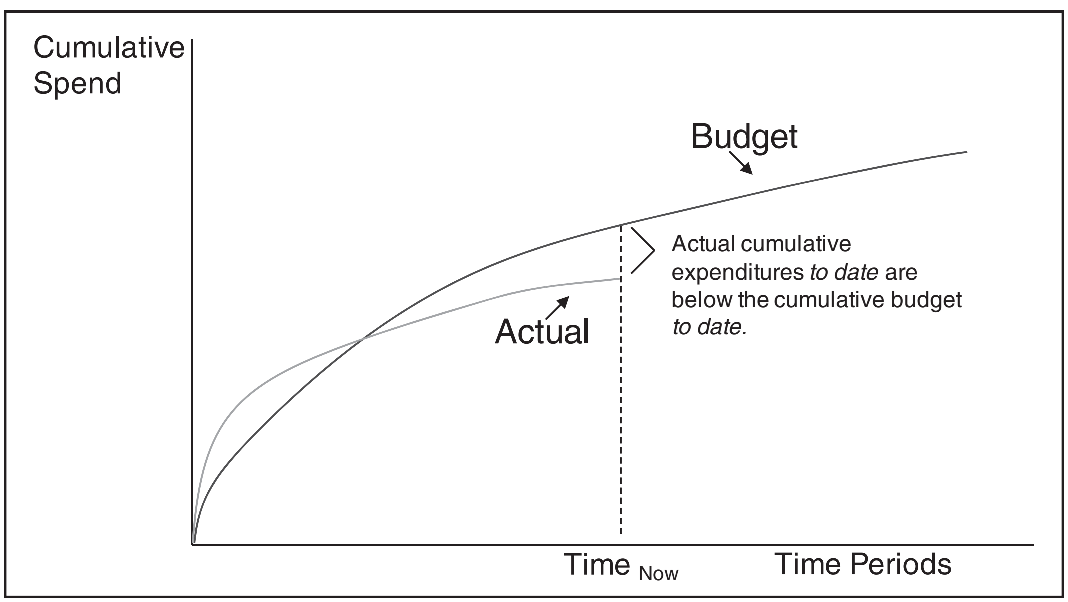

Figure 1. The Spend Plan Approach

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.

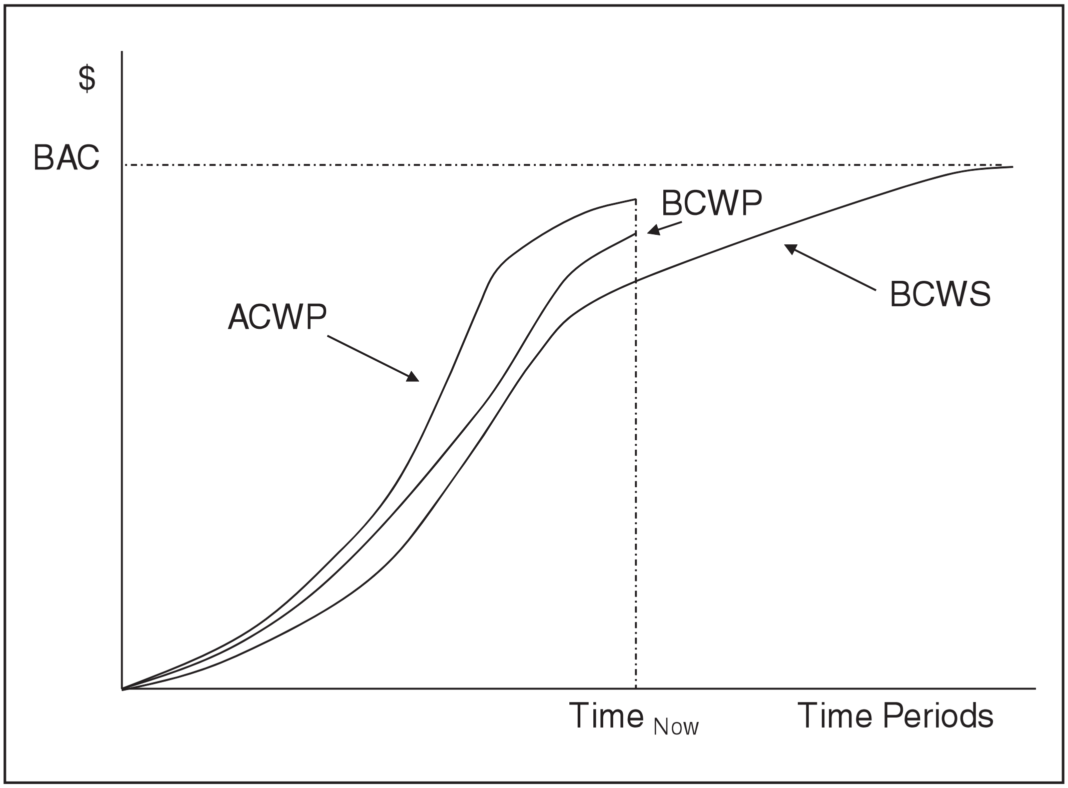

Figure 2. Illustration of EVM Metrics

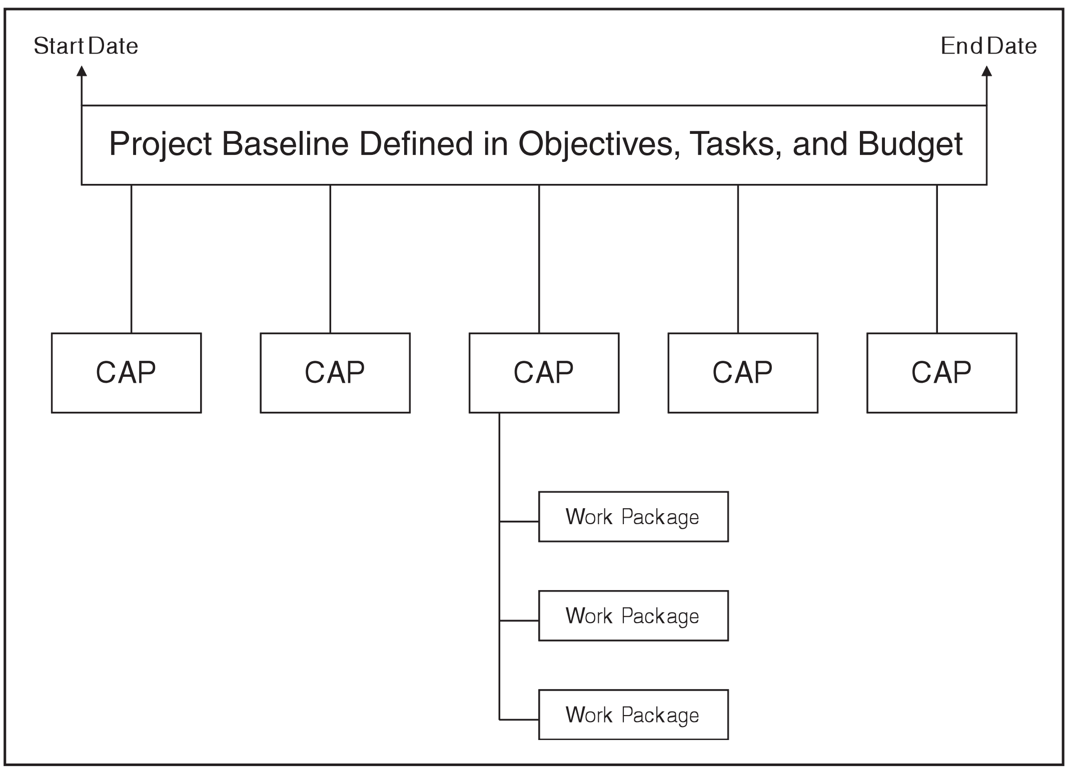

Figure 3. Data and Measurement Structure for Implementing EVM

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.

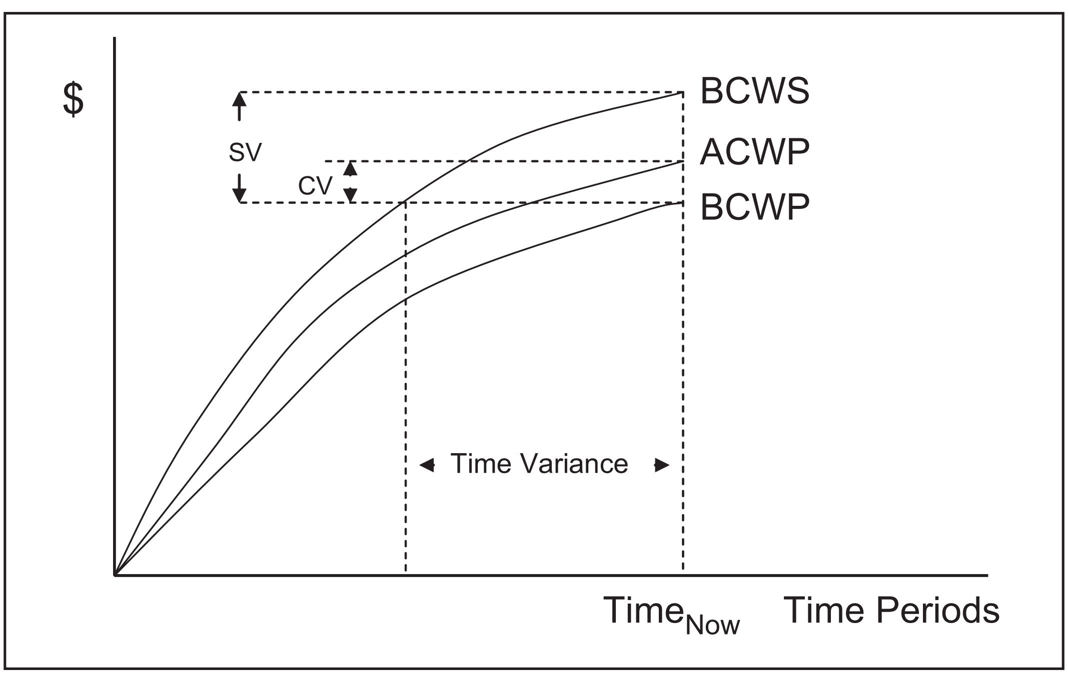

Figure 4. Performance Assessment with EVM Metrics

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.

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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

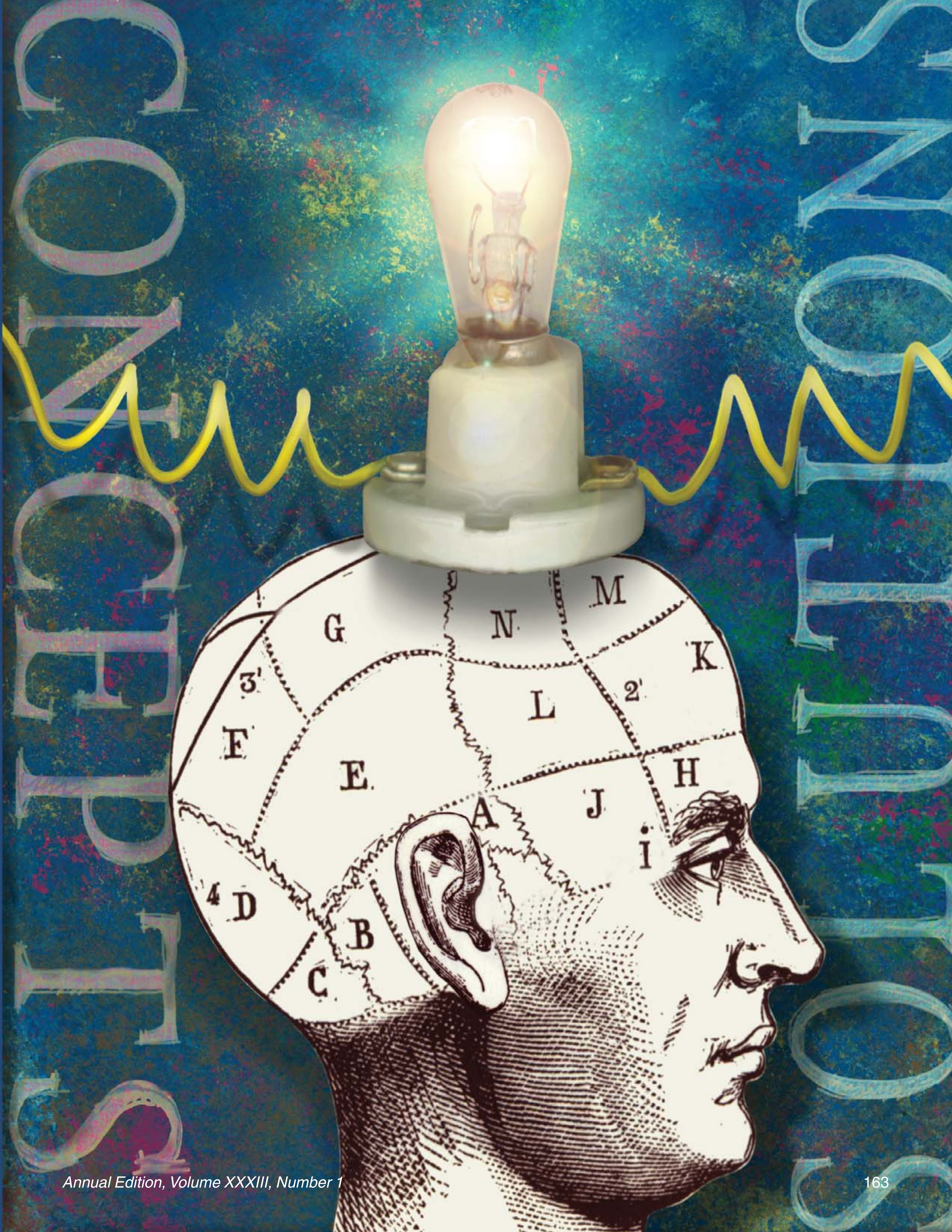
The foundation of the Comprehensive Assessment of Nuclear Sustainment (CANS) analysis was the aggressive use of Air Force Smart Operations for the 21st Century (AFSO21) tools to attack root causes. Though the effort was time constrained and many of the processes were modified to streamline the application,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


CONCEPTS
SOLUTIONS

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

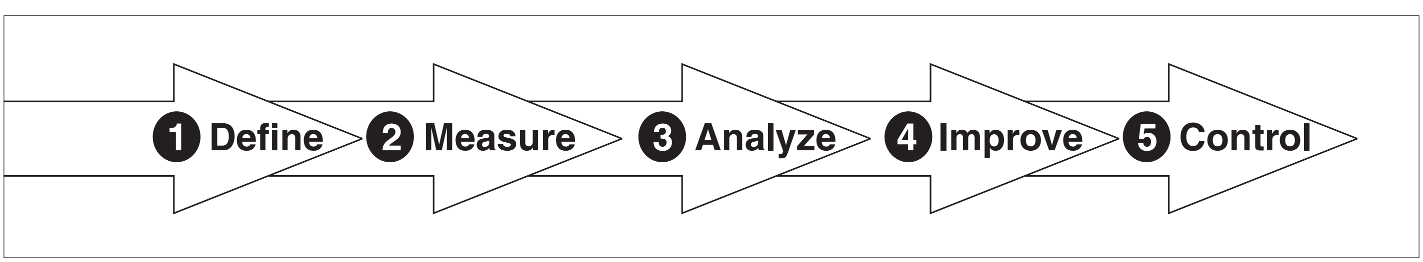


Figure 1. The DMAIC 5-Step Problem Solving Approach[5]

- 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

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

where *F:{0,1}” $\longrightarrow$ R^J, is that of finding a solution* $x^n \in \Omega$ that optimizes the set of objectives $F = (F_1, F_2, ..., F_J)$ *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.

	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

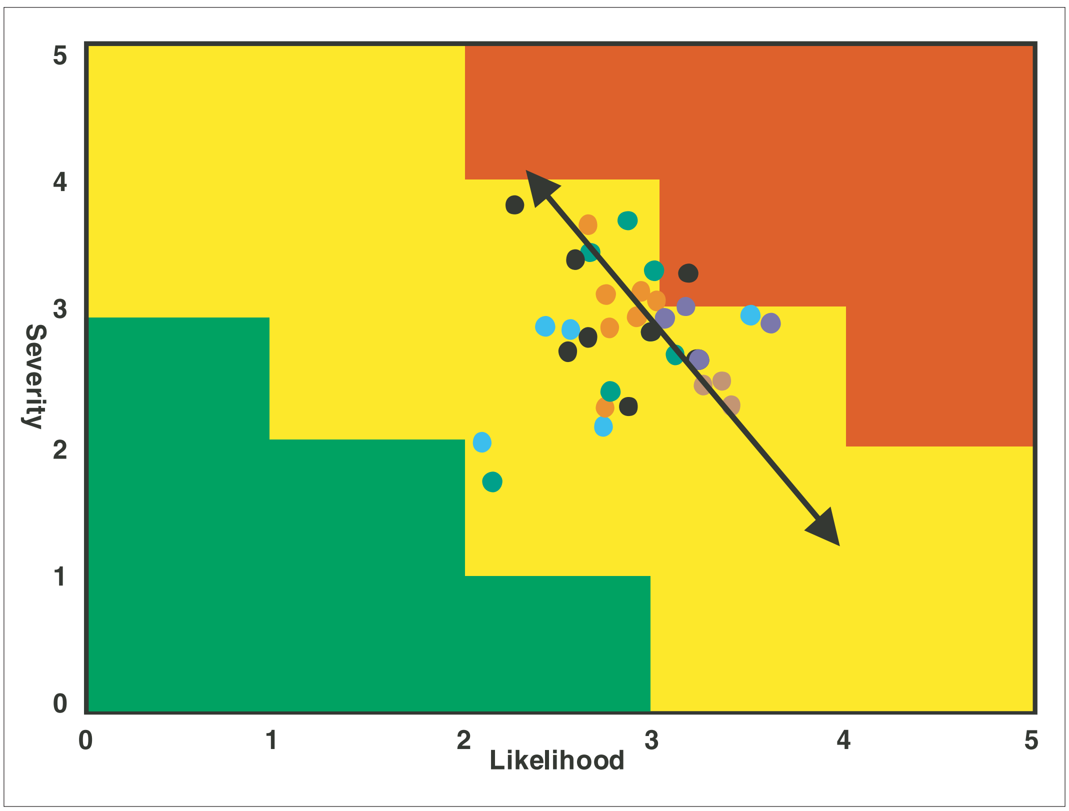


Figure 2. Notional Risk Analysis Output

To combine the objectives, the WSOTOF method requires a predetermined set of weights. In many cases, this can be problematic[18] as it is dependent on subjective judgment of the decisionmaker which may not be available or fixed across the duration of the study. Thus, this step is of particular importance. Additionally, in this particular problem, the determination of weights is even more complex as there are multiple decisionmakers to be considered.

To ensure that multiple decisionmaker preferences are included and considered in the solution, the following method was used. First, a group of senior Air Force leaders was identified as stakeholders for the nuclear sustainment enterprise and defined as the decisionmakers for the multi-objective problem. After each stakeholder provided a set of weights, the problem was solved as follows:

- A simple average of the weights provided by the stakeholders was used as the weights for the problem. However, there was considerable variance in the weighting schemes provided by the stakeholders (see Figure 3 and Table 3) indicating that further investigation was necessary. The distribution of the weights was tested for normality using normal p-p plots and the Kolmogorov-Smirnov (K-S) goodness test for normality. The plots and the K-S test indicate failing to reject the null hypothesis that the weights are normally distributed. Though in this case, parametric statistics would then be applicable, the use of a simple mean may not be adequate because of the high degree of variance.
- The weights were further analyzed as follows. A sensitivity analysis was conducted to determine the impact of the weighting scheme on the overall prioritized solution. It was found that the top priority issues in the prioritization solution were relatively impervious to the weighting scheme. A prioritized list of findings was determined for each decisionmaker's preference of weights and was then examined against the others. In this case, it was also found that the top priority issues did not vary much over the various weighting schemes. The average of the ranks assigned from each weighting scheme was determined for each finding, and was used to assign its final rank.

Once the objectives have been combined, any applicable optimization method can be used to determine the prioritized list of findings. In this case, 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.

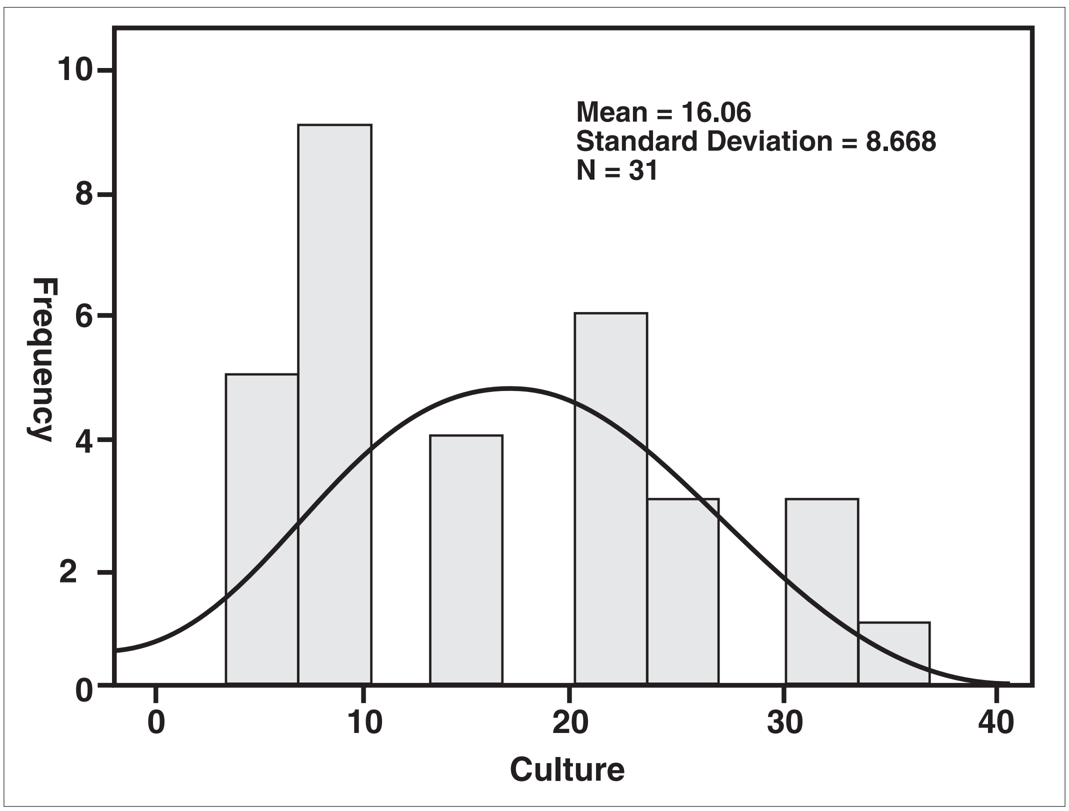


Figure 3. Histogram of Weights Assigned to Culture

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.

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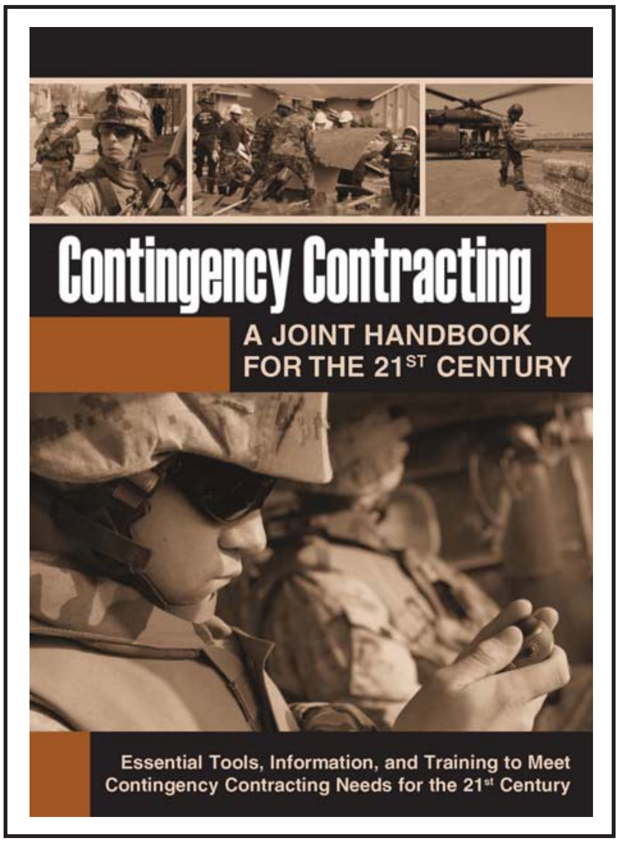
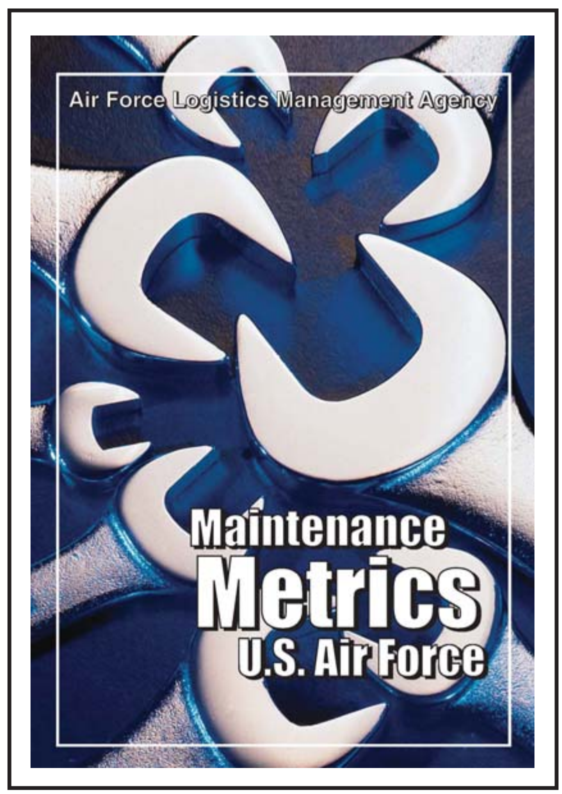


maintenance metrics

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.



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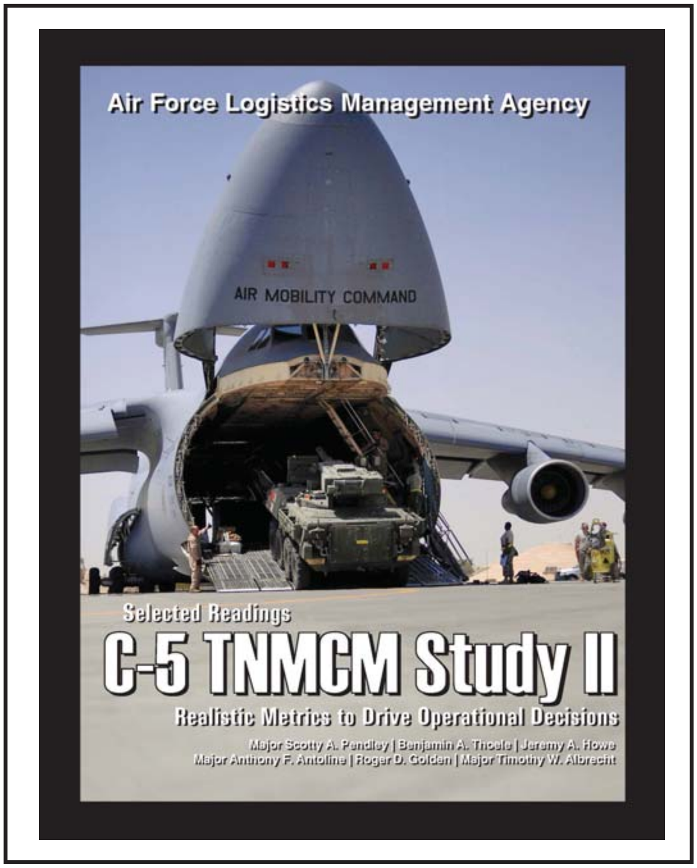
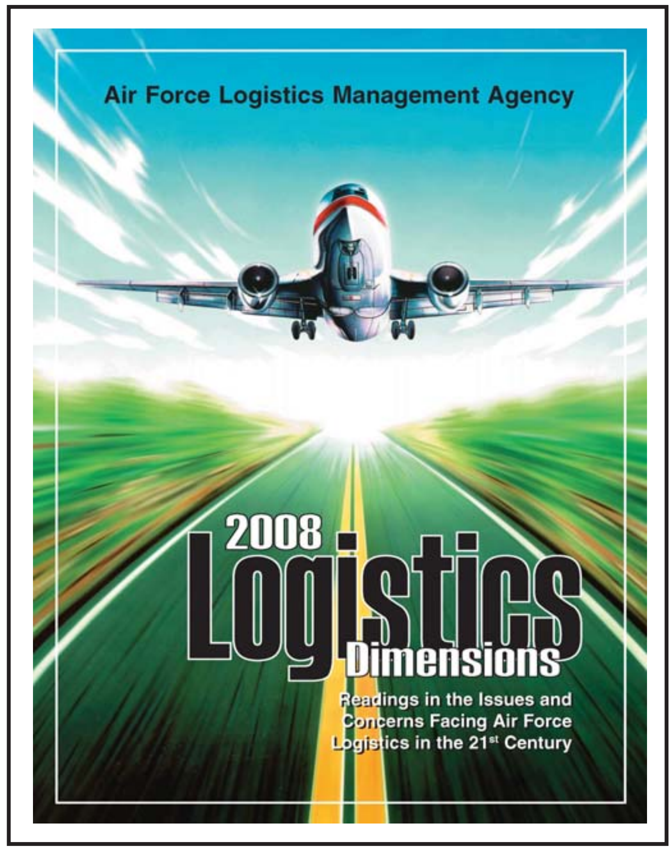


C-5 TNMCM study II

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.

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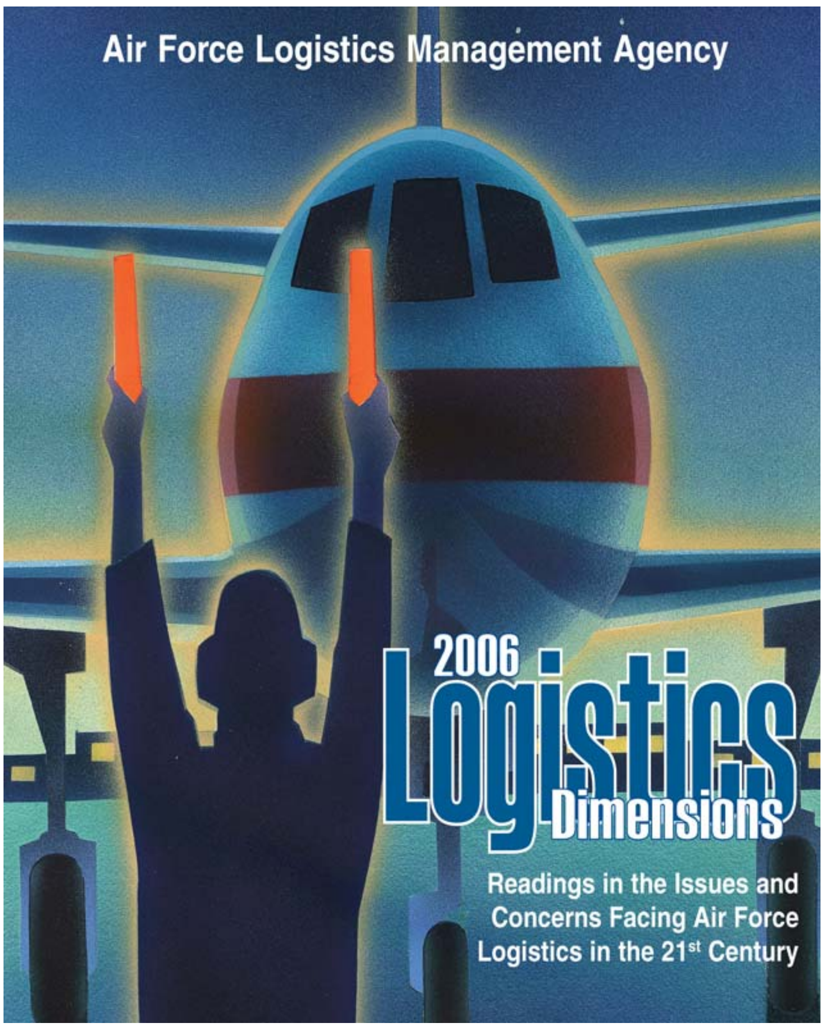
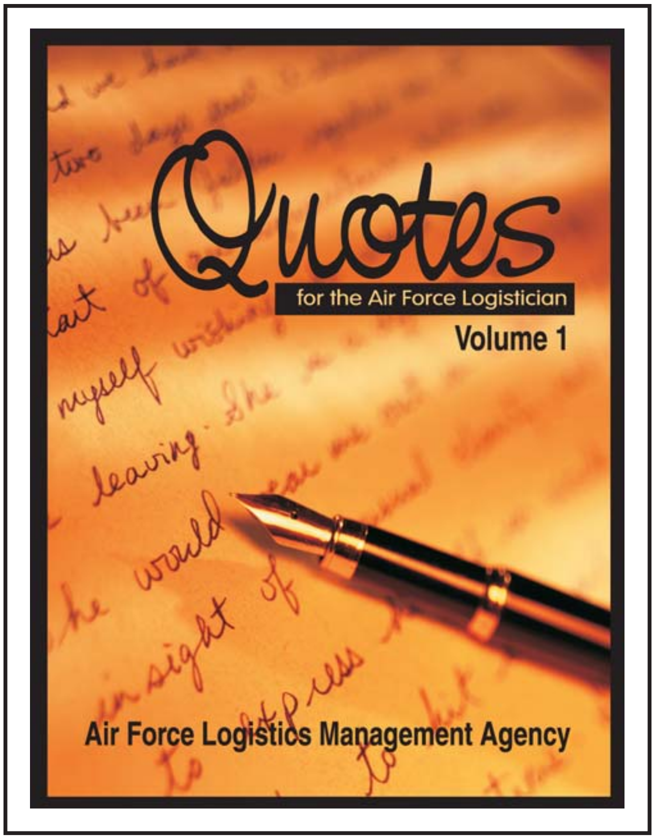


2006 logistics dimensions

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.



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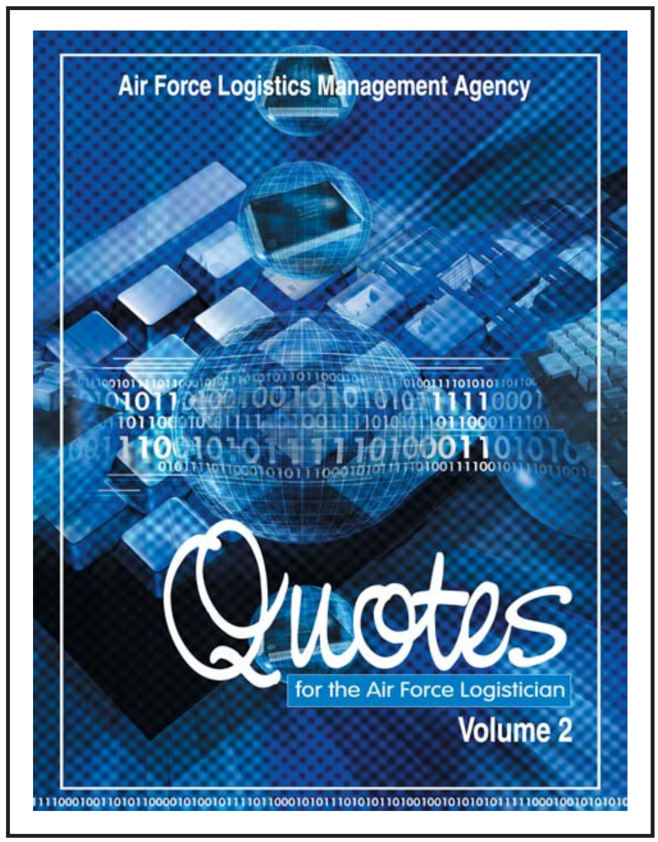

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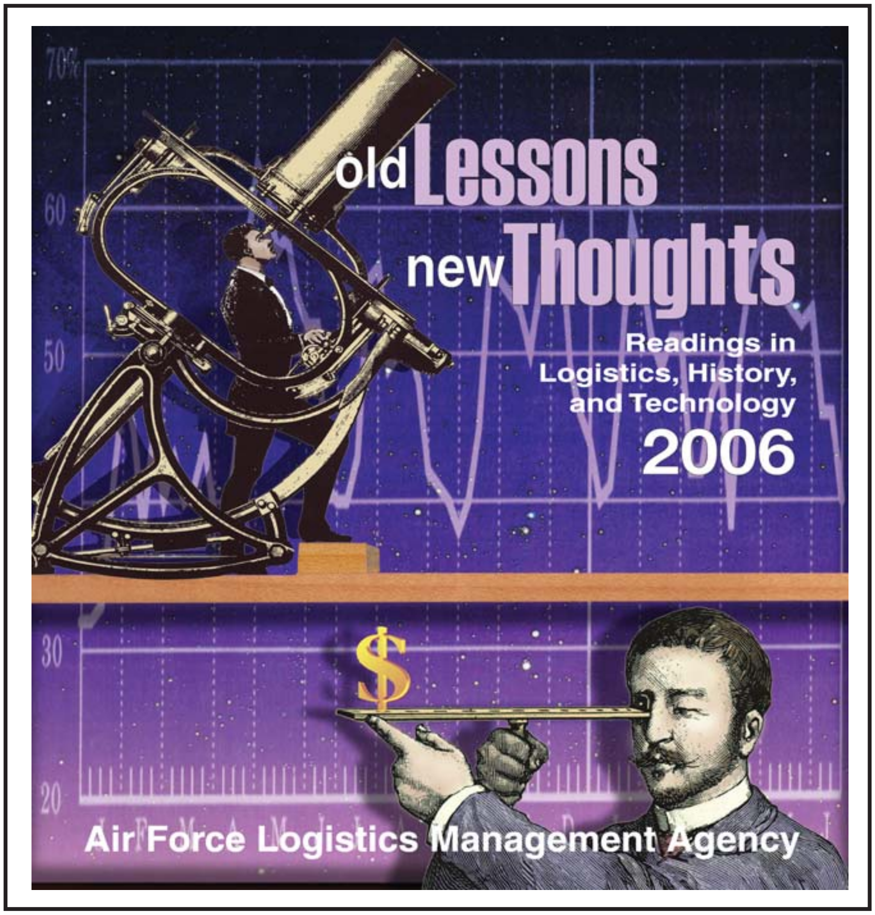

old lessons new thoughts 2006

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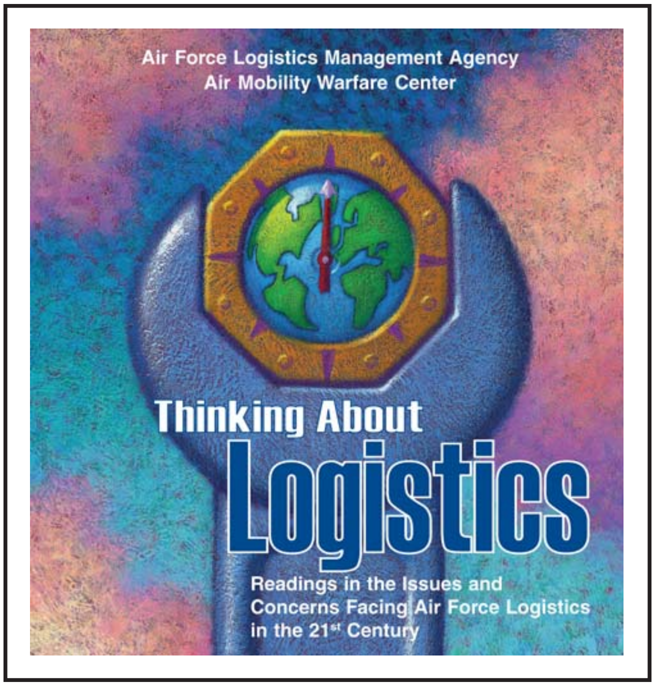

thinking about logistics

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.

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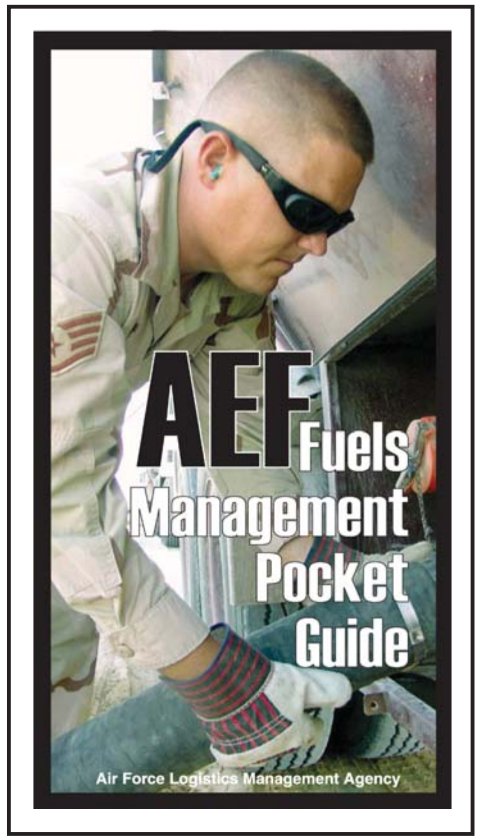

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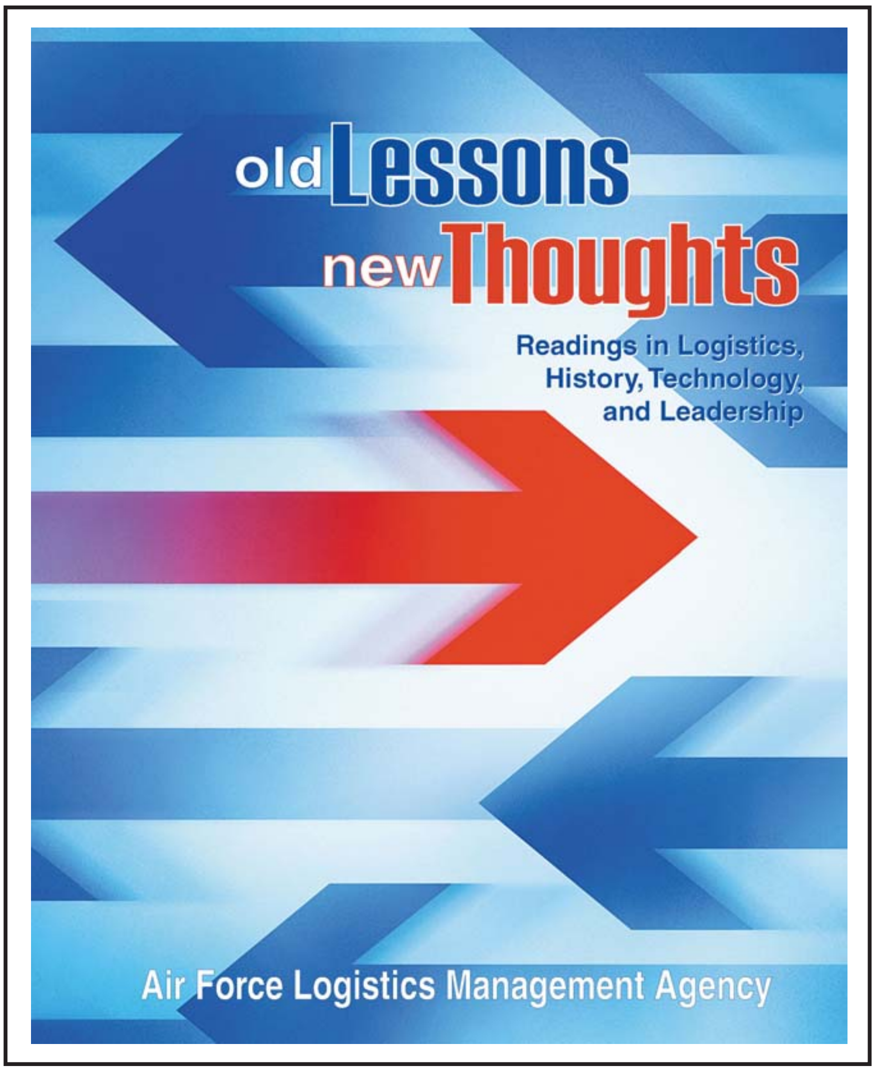
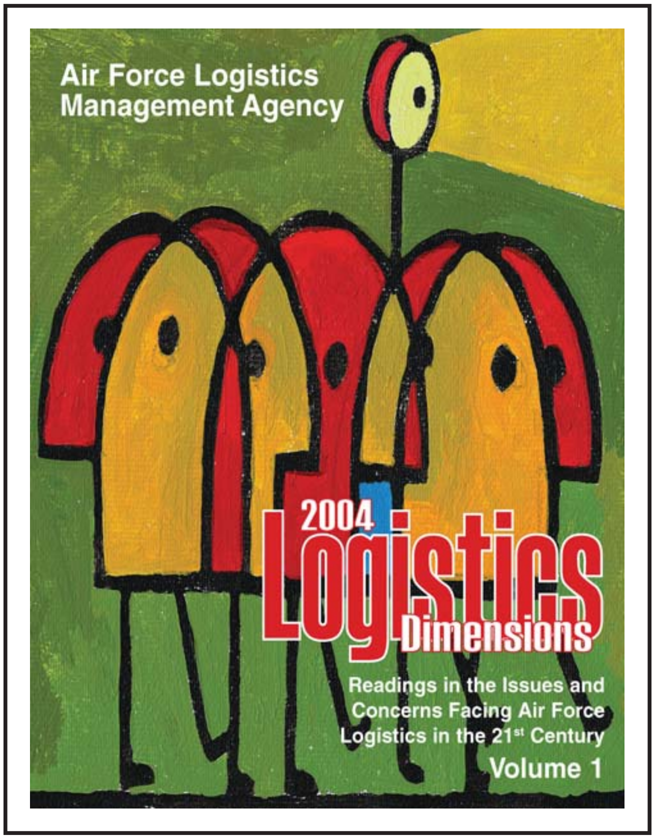


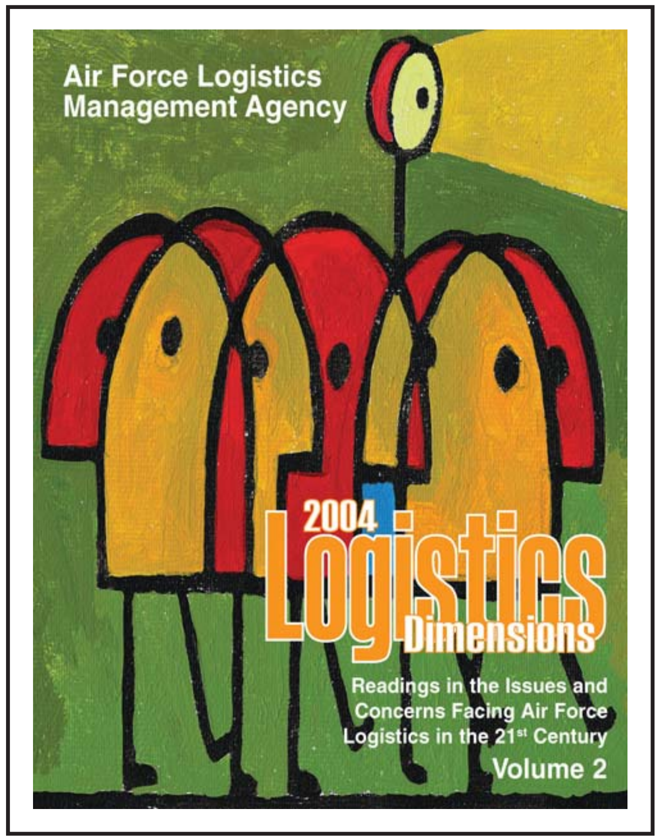
old lessons, new thoughts

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 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.



2004 logistics dimensions, volume 1

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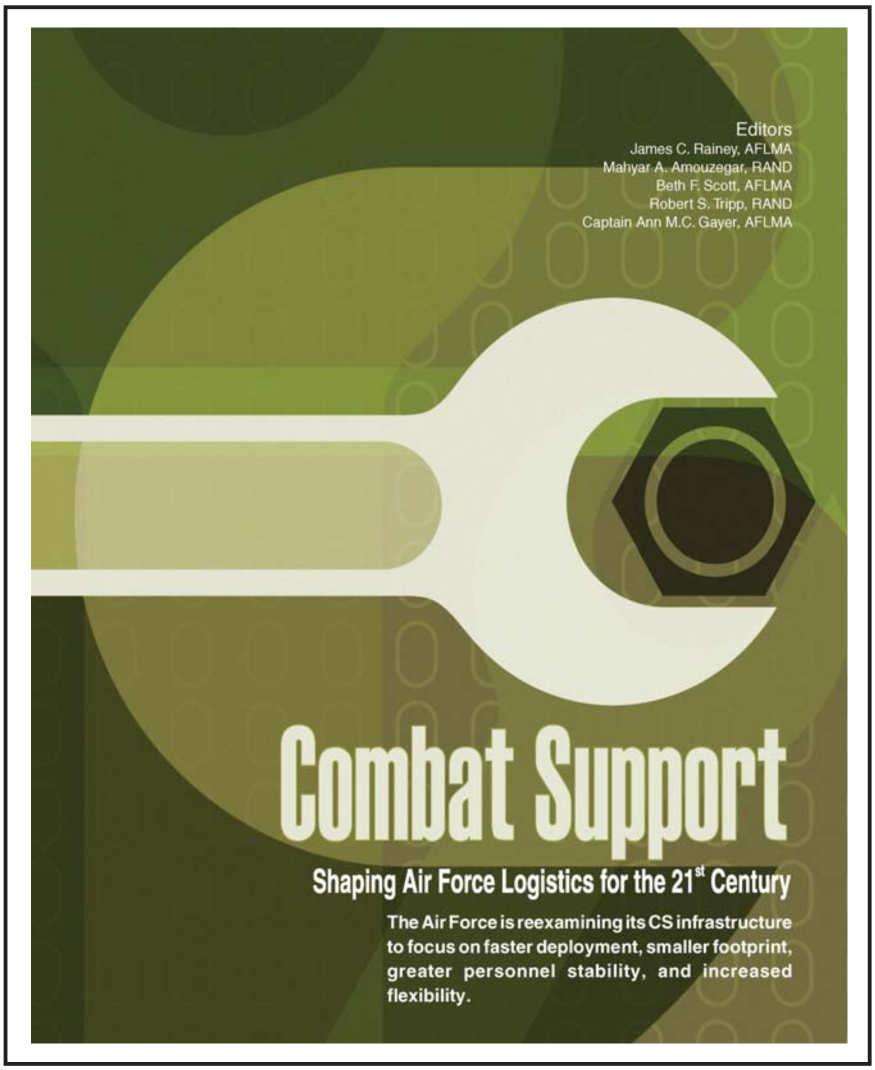
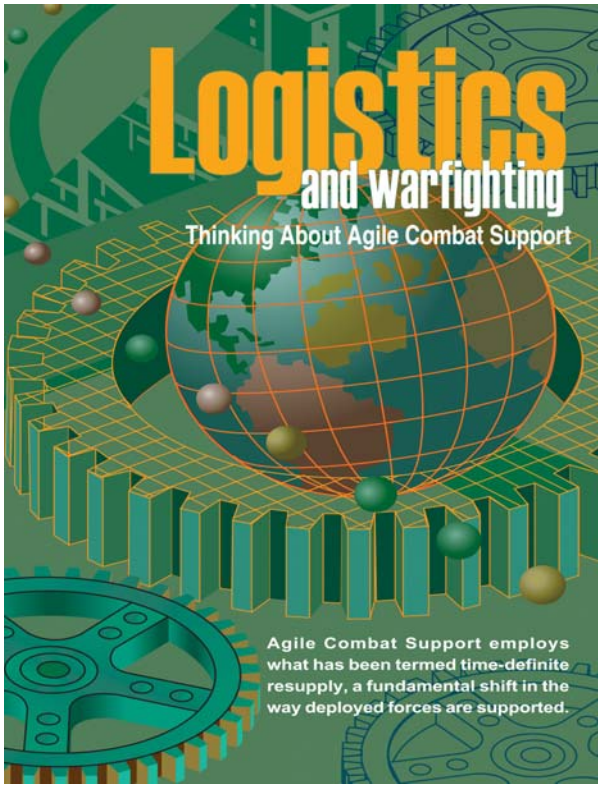


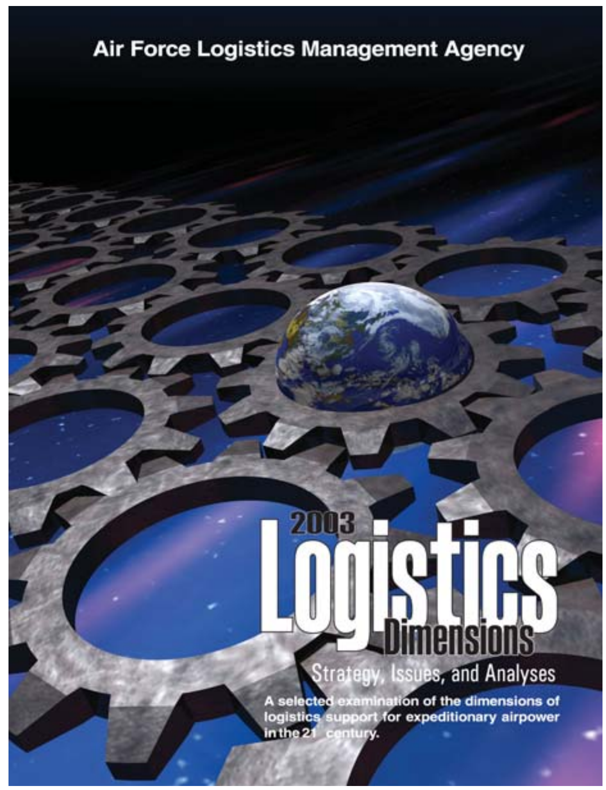
combat support

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.



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.



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.

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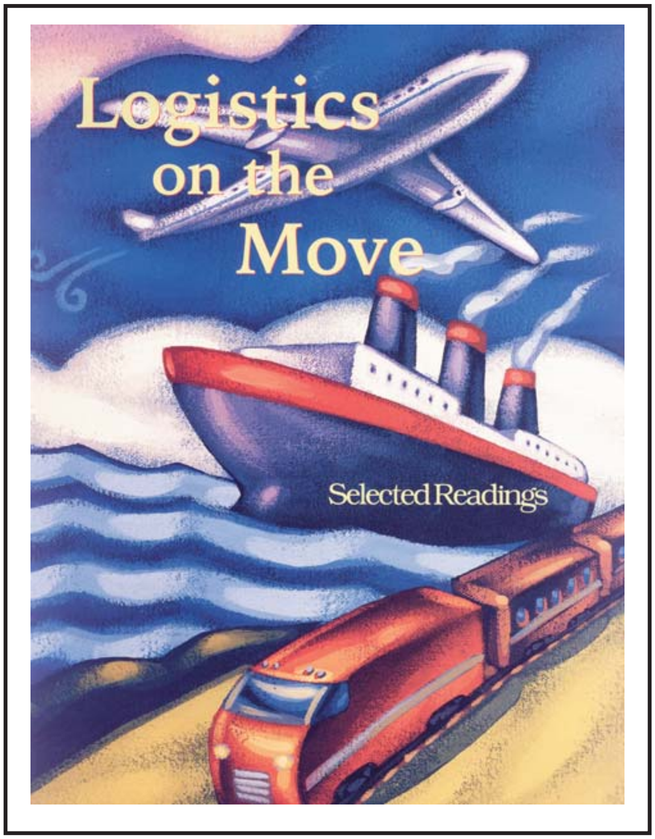
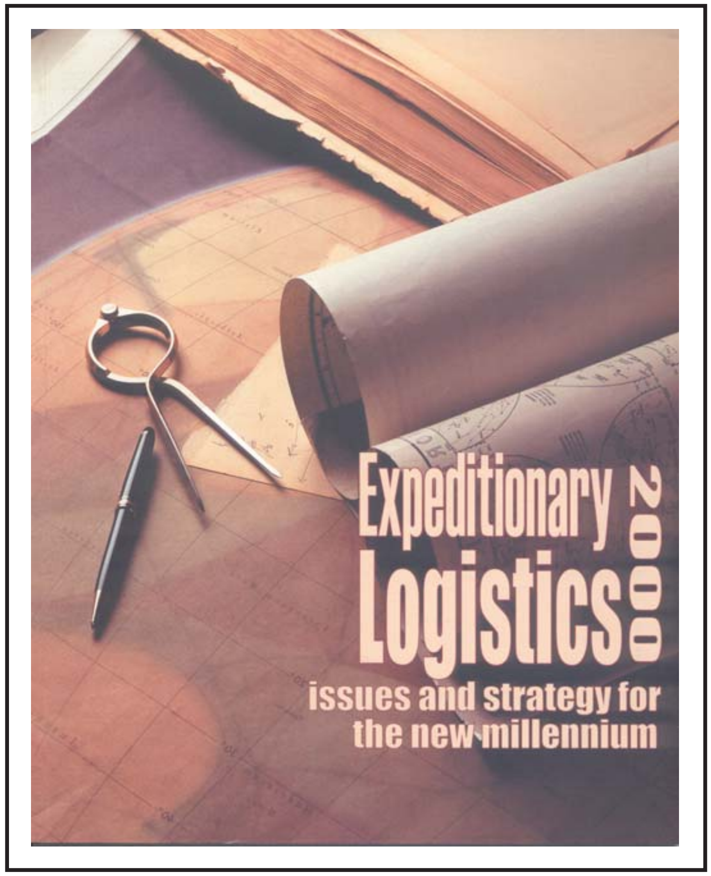
contractors on the battlefield

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*.



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.

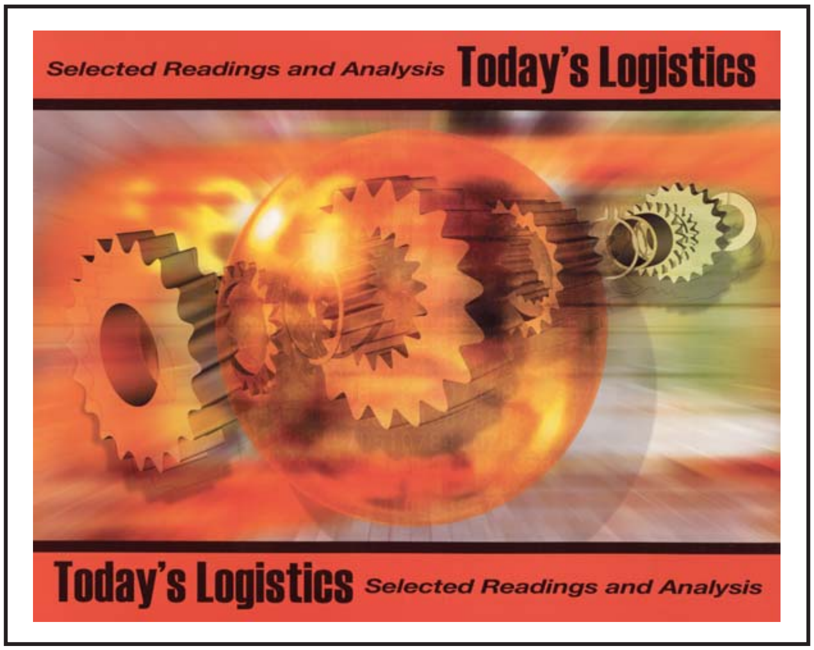


logistics on the move

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.

Many of our books and monographs are now out of print. However, they are available in electronic format to support continuing Air Force professional military education requirements. They can be viewed or downloaded at the AFJL WWW site (http://www.aflma.hq.af.mil/lgj/Afjlhome.html) All are in the portable document format. Files range in size from 1.5 meg to 10 meg.

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.

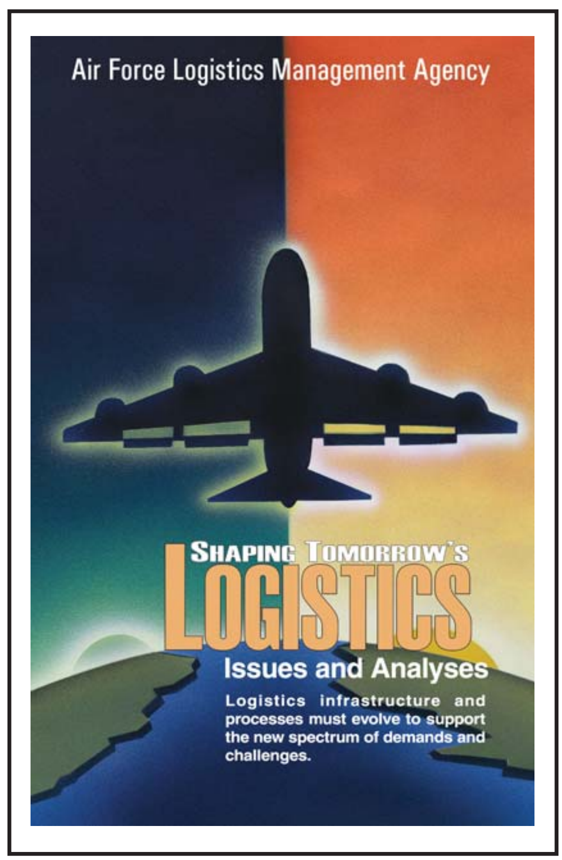


today's logistics

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.**

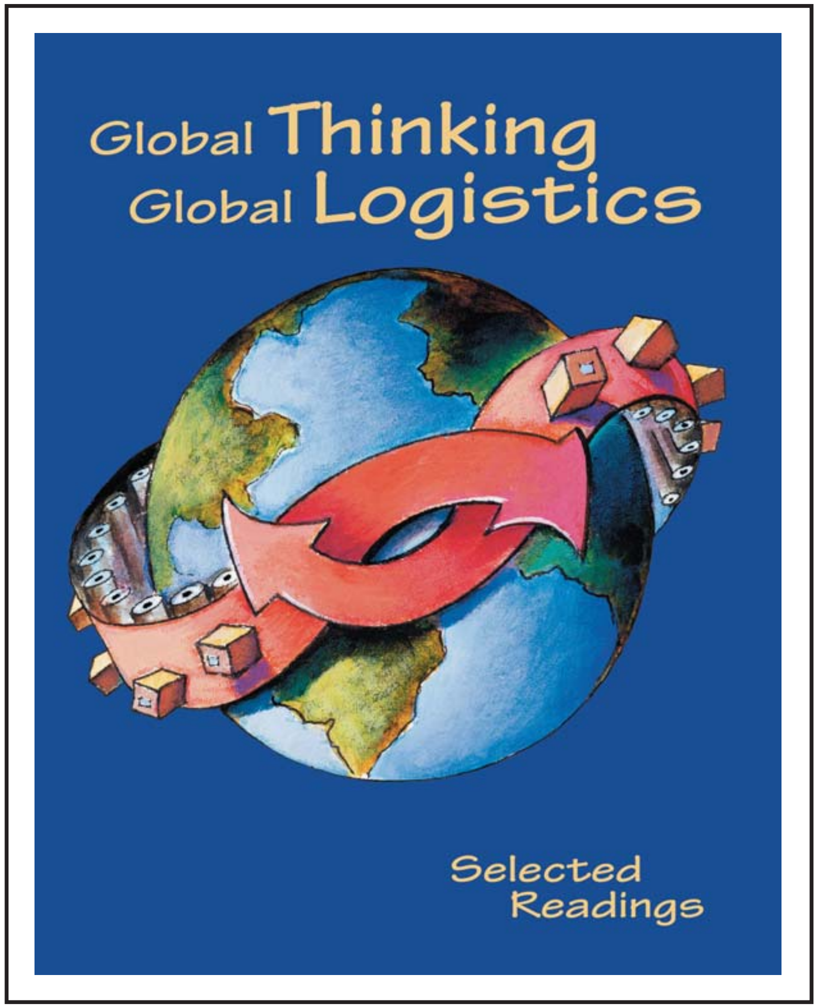
shaping tomorrow's logistics

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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education, training, and mentoring

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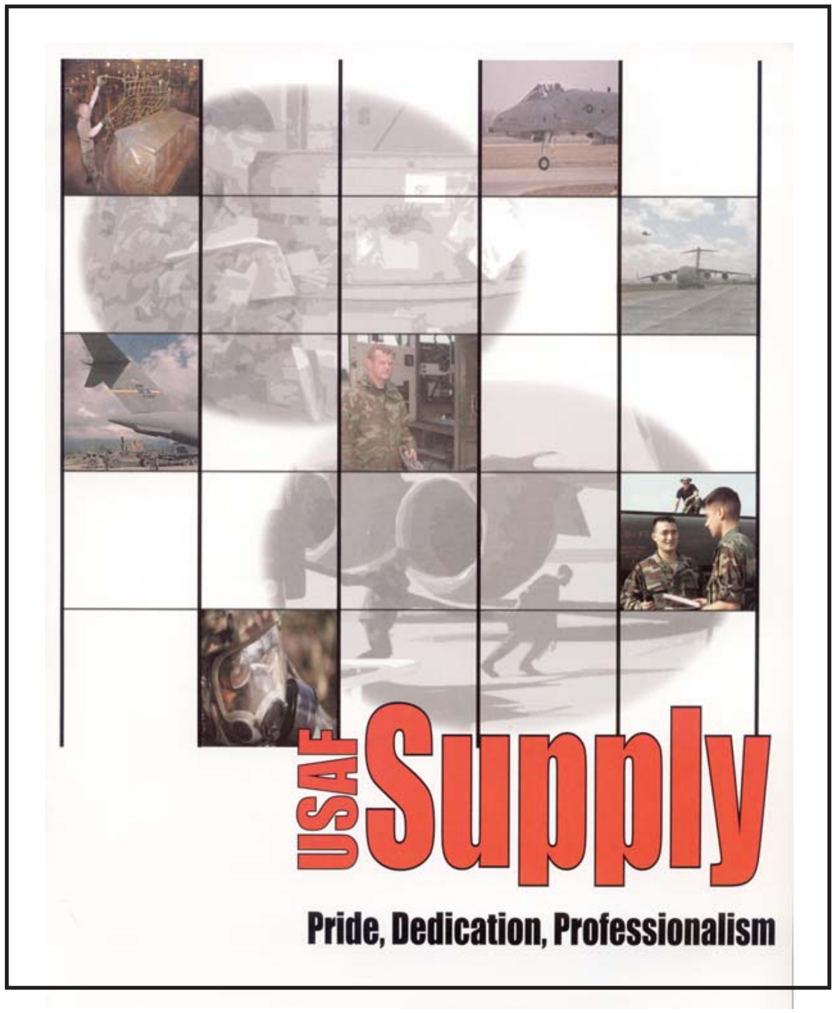
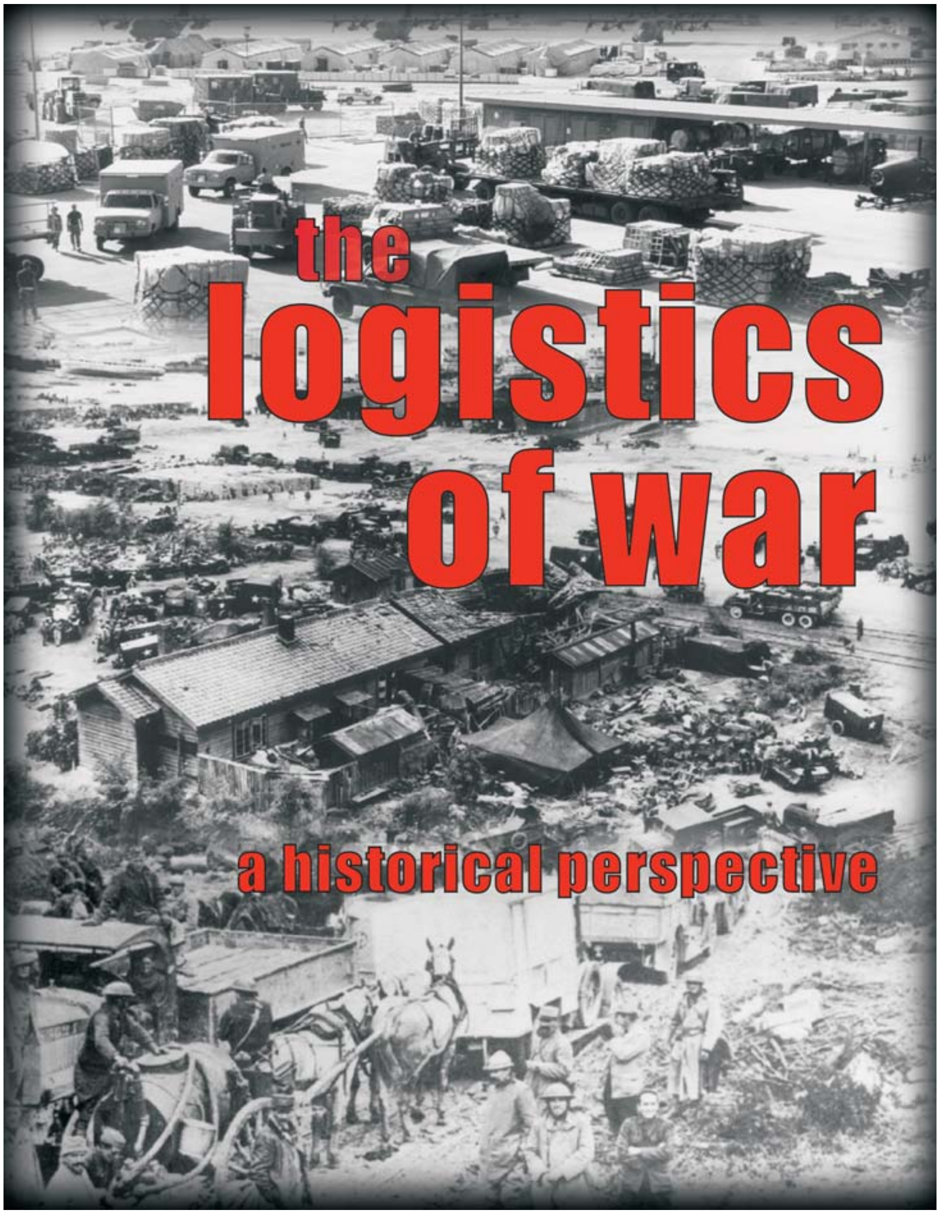


usaf supply

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.

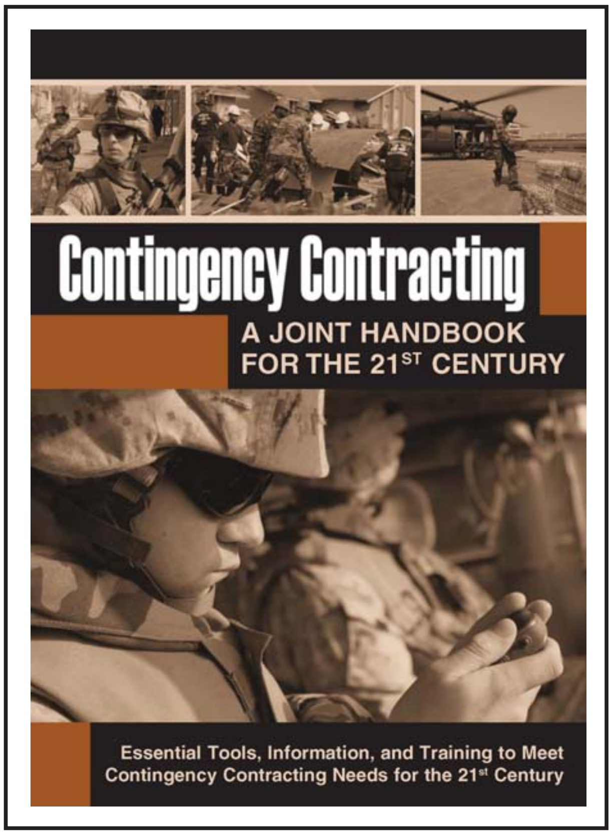
We produce and publish a variety of high-impact publications—books, monographs, reading lists, and reports. That's part of our mission—address logistics issues, ideas, research, and information for aerospace forces.

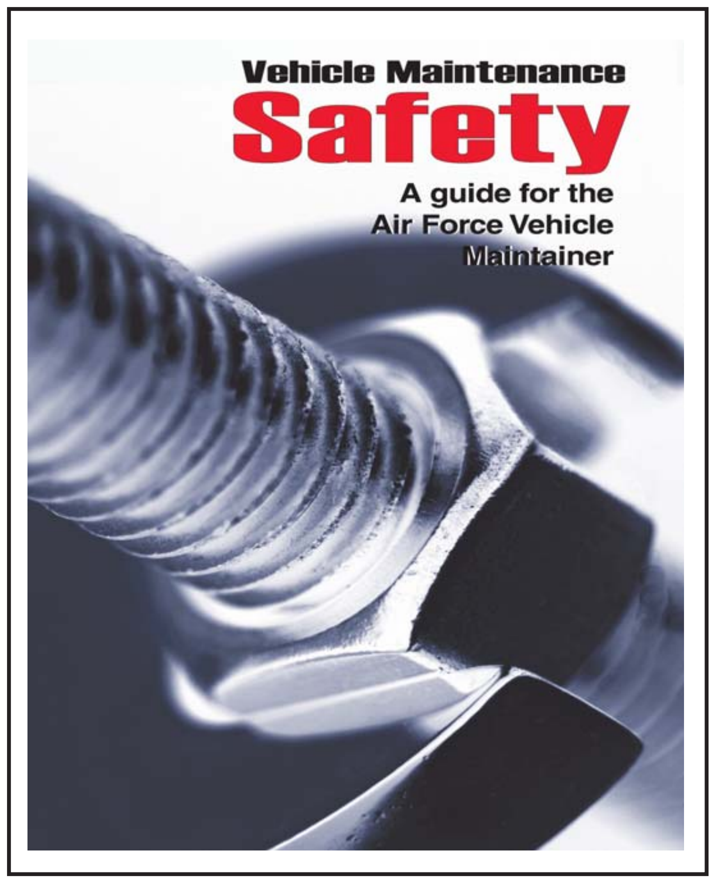
what you need, when you need it

Guidebooks and Special References

vehicle maintenance safety handbook

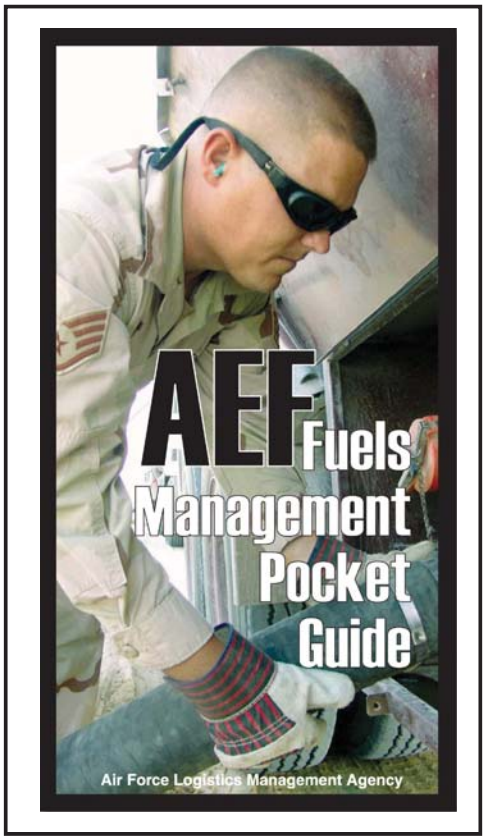
The *Vehicle Maintenance Safety Handbook* was produced in partnership with Air Staff and MAJCOM vehicle maintenance subject-matter experts for use in the Air Force 2T3 vehicle maintenance community. It's designed to improve safety awareness in the Air Force vehicle maintenance community. It provides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





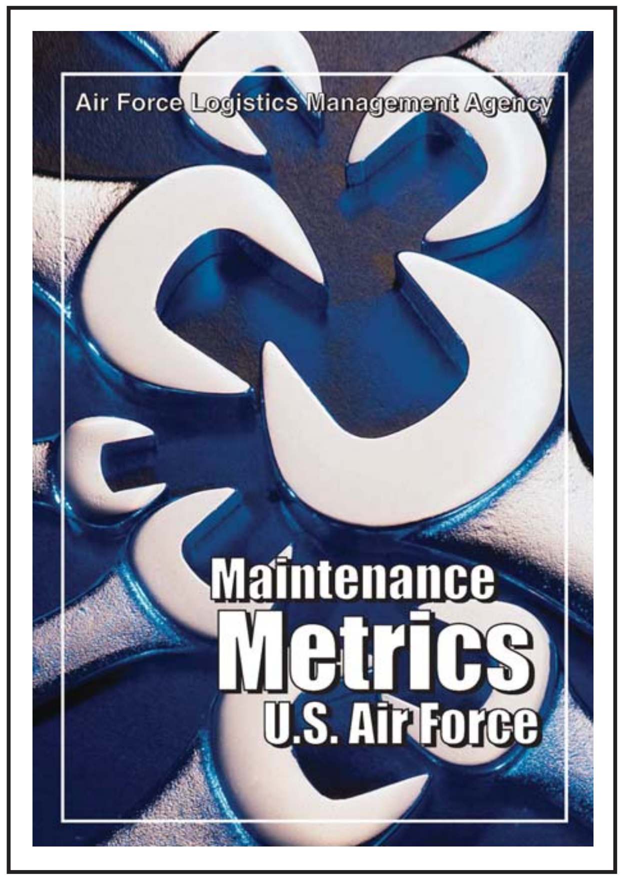
contingency contracting

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.



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.

Our guidebooks and special reference material are in high-impact format and meet defined Air Force needs. They're also publications that communicate and will be used where they're needed and when they're needed. They may be ordered by contacting the Office of the Air Force Journal of Logistics or the applicable AFLMA division. There are limited quantities of some of these items.