



PROJECT AIR FORCE

This report documents the history of the interactions between RAND Corporation logistics researchers and Air Force leaders over more than 40 years to inform decisions involving logistics planning, programming, and budgeting and to develop, maintain, and evolve an approach for improving the Air Force logistics system. The narrative covers a period in which the demands made on the Air Force logistics system became more dynamic, complex, and costly—an era in which increasingly sophisticated weapons were joined by a growing appreciation for the importance of readiness, sustainability, system reliability, and uncertainty in Air Force and RAND thinking about military logistics.

These reflections illustrate why the impact of expert research and analysis on entities as large and complex as the Air Force logistics system is sometimes not immediate. Although the path to impact is not always straightforward, a vision of clear principles can help guide logistics and other forms of research over time. By retaining deep knowledge and expertise in logistics and in the overarching themes that have guided RAND's logistics research for the Air Force over the past 40 years, RAND researchers can be ready to engage on these key themes and enduring questions over the long term.

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ROBERT S. TRIPP

The Line Between Disorder and Order

Reflections on RAND's Role in the Evolution of Air Force Logistics Thought and Practice



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Foreword

The impetus for this report was an email exchange with retired General James P. Mullins, former commander of the U.S. Air Force Logistics Command, in the fall of 2017 about the RAND Corporation's contributions to Air Force logistics policies and procedures stretching over nearly seven decades. I shared General Mullins' note with several others in the RAND family, including the author of this report, Bob Tripp. Bob had served under General Mullins during his own Air Force career and later was a key member of the logistics research staff at RAND. Ultimately, I asked Bob to document the history of the interaction between RAND logistics researchers and Air Force leaders over the past several decades.

The narrative in this report covers a 40-year period in which the demands made on the Air Force logistics system became more dynamic, complex, and costly—an era in which increasingly sophisticated weapons were joined by a growing appreciation for the importance of readiness, sustainability, system reliability, and uncertainty in Air Force and RAND thinking about military logistics. The narrative describes the close collaboration between the Air Force and RAND as both took on the challenges of those demands. And it makes special note of the vision and formative leadership of General Mullins in providing the conceptual framework for the four-decade effort.

Left unspoken, but of no less importance to the success of the collaboration, has been the long-term institutional relationship between the Air Force and RAND, instantiated in the federally funded research and development center (FFRDC) at RAND known as RAND Project AIR FORCE. The FFRDC model—invented by the Air Force in

the aftermath of World War II—links a government organization with a qualified research organization to meet special long-term research needs. While the formal link is a contract and statement of work, the relationship takes its strength from trust and close interaction between the parties. In the case of Project AIR FORCE, Air Force leadership actively participates each year in the development of an effective research plan, closely collaborates to enable its execution, and provides crucial support for dissemination and implementation of key research findings and recommendations.

RAND has maintained this FFRDC linkage with the Air Force since the founding of both institutions in the 1940s. This type of sustained effort on long-term challenges leads to meaningful accumulation of data, tools, and insights—cycles that generate successive rounds of improved processes and policies. Bob’s admirable depiction of the evolution of key management tools and policies—METRIC and Dyna-METRIC, for example—gives an ample demonstration of this cycle of improvement, and even the decades of work described here drew on much earlier efforts on supply and maintenance of strategic bomber and refueling forces.

In the best of instances, as with the logistics efforts described in this narrative, a long-term partnership grows among all of the participants, both RAND and the Air Force: mutual responsibilities, a shared belief in the importance of the work and the value of cooperation, and the freedom to challenge ideas and emerge with a common understanding. As a one-time participant in and continuous observer of the efforts described here, I take pride in the joint accomplishments and the role that RAND has played and will continue to play in the evolution of logistics policy and processes. I am grateful to Bob Tripp for his dedication in providing this narrative and to General Mullins for reminding us of the power of our joint efforts. I believe that the narrative and its insights will be of deep interest to RAND and Air Force logisticians and leaders. There certainly will be no dearth of important and interesting challenges to face together in the future!

Michael D. Rich
 president and chief executive officer, RAND Corporation

Preface

As Michael Rich indicated in the Foreword, the email interchanges between me, Michael, General Mullins, and several RAND senior leaders offered an interesting and important view of how RAND research has informed and continues to inform the evolution of Air Force logistics thinking. They appreciated the insights into how RAND's sustained interactions with Air Force leaders and the adoption of a vision for proactive logistics have established a foundation for structuring logistics research within RAND over a considerable period. They encouraged me to share my reflections on this topic in a research report. They felt that these reflections could illustrate how and why it takes considerable time for RAND's research to have an impact and lead to changes in a system as large and complex as the Air Force logistics system. The report would also show that, while the path to impact is not always straightforward, a vision of clear principles can help guide logistics and other forms of research over time. As a result of this encouragement and interest, I offer my reflections on these topics.

My hope is that these remarks will be useful to program managers and researchers interested in researching logistics problem sets over time. This report should also be of interest to junior researchers and others who are new to RAND or new to the policy research field and who want to gain a better understanding of how policy research projects achieve impact. These reflections might be particularly helpful to those setting the RAND research agenda and those who are developing interests in working in a field for a sustained period.

RAND Project AIR FORCE

RAND Project AIR FORCE (PAF), a division of the RAND Corporation, is the U.S. Air Force's federally funded research and development center for studies and analyses. PAF provides the Air Force with independent analyses of policy alternatives affecting the development, employment, combat readiness, and support of current and future air, space, and cyber forces. Research is conducted in four programs: Strategy and Doctrine; Force Modernization and Employment; Manpower, Personnel, and Training; and Resource Management. The research reported here was prepared under contract FA7014-16-D-1000.

Additional information about PAF is available on our website: www.rand.org/paf/

This report documents work originally shared with the U.S. Air Force over many decades. Some of the more important works that this report draws upon are listed in the annotated bibliography. This report was reviewed by formal peer reviewers and U.S. Air Force subject-matter experts to ensure accuracy of attribution to specific works and a proper perspective of the historical accounts.

Contents

Foreword iii

Preface v

Figures ix

Acknowledgments xi

Abbreviations xv

CHAPTER ONE

Introduction 1

CHAPTER TWO

**Prologue: Some Ideas That Shaped My Early Thinking About Air
Force Logistics and Prepared Me to Act Given the Opportunity...** 3

CHAPTER THREE

**1976 to 1979: Understanding How Logistics Policies, Processes,
and Postures Impact Operationally Relevant Metrics, Costs,
and Risks** 7

CHAPTER FOUR

**1979 to 1982: Integrating Logistics Capabilities and Constraints
Within Wartime Planning and Readiness Assessments** 13

CHAPTER FIVE

**1982 to 1985: Developing Proactive Weapon System Readiness
Assessments, LOG C2 Concepts, and Efforts to Address
Uncertainty in Logistics System Designs** 19

CHAPTER SIX

1985 to 1987: Implementing RAND Contributions to Readiness Assessments and Increasing Emphasis on Incorporating Uncertainty in Logistics Systems 25

CHAPTER SEVEN

1987 to 1992: Building Responsiveness into Logistics System Designs to Cope with Uncertainty 27

CHAPTER EIGHT

1992 to 1996: A Period of Focusing on Logistics Efficiencies, with Less Attention on How Logistics Processes Impact Effectiveness 33

CHAPTER NINE

1996 to 2003: Relating Logistics Postures and Policies to Operational Effects and Costs Across Phases of Operations 37

CHAPTER TEN

2003 to 2011: Expanding Logistics Analyses to Focus on Enterprise-Wide Impacts 47

CHAPTER ELEVEN

2011 to 2014: Reorganization of AFMC and LOG C2 Stagnation..... 55

CHAPTER TWELVE

2012 to the Present: Examining Logistics Under Attack 57

CHAPTER THIRTEEN

Moving Forward: Designing Logistics Systems to Be Responsive to Unanticipated Events 65

Annotated Bibliography 69

Figures

4.1. Improved Logistics Planning, Execution, Monitoring, and Control Processes Identified in the PACAF Combat Support Capability Management System..... 15

7.1. The CLOUT C2 System 31

9.1. Supply-Side, Demand-Side, and Neutral Integrator Roles in Enhanced LOGISTICS Closed-Loop Planning, Execution, Monitoring, and Control System Processes 41

9.2. The LOG C2 Operational Architecture Shows How Enhanced Logistics Planning, Execution, Monitoring, and Control Processes Impact Processes Across the Entire PPBES..... 44

10.1. The AFMC Combat Support Planning and Execution System Used WSMIS Capabilities Developed in 1985..... 49

10.2. The LOG C2 Structure Tested in ALEX..... 51

12.1. The Combat Operations in Denied Environments Analytic Framework..... 59

Acknowledgments

This document reflects the contributions of many people in the Air Force and at RAND for building and sustaining relationships that have facilitated the ability of RAND researchers to make an impact on Air Force thinking and actions to enhance the logistics system over a considerable time horizon. The Air Force logistics processes, policies, procedures, organizations, training, information systems, and analytic capabilities are vast and deal with a very complex system. Over the years, much of RAND's logistics research has dealt with understanding and evaluating how logistics system options impact combat power, costs, and risks in enabling operations over the spectrum of operating environments—from training and steady-state operations to war-time engagements with near-peer adversaries. My remarks describe the important roles that specific people have played in influencing the evolution of Air Force thinking about logistics over the last 40 years.

There are many Air Force leaders who have influenced RAND's engagement in thinking about logistics system design options and the associated need for logistics analysis. There are too many to mention, but I want to note the special contributions of the following, who have played key roles in supporting the research streams discussed in this paper and in implementing the research findings and tools within the Air Force. In particular, I want to thank General James Mullins (USAF, retired), former commander of Air Force Logistics Command; Lt Gen Terry Gabreski (USAF, retired), former vice commander of Air Force Materiel Command; Lt Gen Michael Zettler (USAF, retired), former DCS for Logistics and Engineering at the Air Staff; Maj Gen Bob

McMahon (USAF, retired), former commander of Warner-Robbins ALC; General John Jumper (USAF, retired), former Air Force Chief of Staff; General Larry Welch (USAF, retired), former Air Force Chief of Staff; Lt Gen Bob Elder (USAF, retired), former 8th Air Force commander; Maj Gen Duane Jones (USAF, retired), former Director of Logistics Plans at the Air Staff; Col Mike Weitzel (USAF, retired), former AFCENT A4; Lt Gen Ted Kresge (USAF, retired), former PACAF vice commander; Maj Gen Mark Dillon (USAF, retired), former PACAF vice commander; General Terrence O'Shaughnessy, former PACAF commander; General Hawk Carlisle (USAF, retired), former PACAF commander; Grover Dunn (retired), former SES, AF/A4I; Lorna Estep, SES, AFIMSC/CD; and Carl Rehberg (retired), former GM15, Asia-Pacific Desk, Plans and Programs, HQ USAF.

There are also a great number of researchers and thought leaders at RAND who have gained a deep understanding of the principles discussed in this paper, have supported research in the themes outlined below, and, at important times, have brought key logistics concepts back into analyses and refocused Air Force leadership attention on them. Once again, there are too many to mention, but I note the important contributions of the following: Irv Cohen, Hy Shulman, Michael Rich, Dick Hillestad, Ray Pyles, Bob Roll, Laura Baldwin, Ron McGarvey, Eric Peltz, Amatzia Feinberg, Ben Van Roo, Jim Masters, John Drew, Kristin Lynch, Jim Leftwich, Dave George, Brent Thomas, Drew Karode, Rachel Costello, Mahyar Amouzegar, Jacob Heim, Pat Mills, Don Snyder, and all the Resource Management Program (RMP) managers and directors of PAF over the past 40 years. Each of these people have contributed thinking on how to formulate and conduct RAND logistics research projects that has had an impact on Air Force logistics thinking.

Influencing Air Force leadership thinking and having Air Force leaders rely on RAND to shed light on difficult and pressing problems are key to RAND's goal of having impact. Effective interaction is critical to impacting Air Force decisions, and Natalie Crawford, vice president and director of RAND Project AIR FORCE from 1997 to 2006, continues to set the example for all RAND researchers in this area.

I thank Ted Harshberger and Obaid Younossi for their encouragement for writing this document and for providing the time necessary for me to put these thoughts down on paper.

I also thank Kristin Leuschner for helping me to organize and communicate these reflections and Bob DeFeo for assembling and organizing the annotated bibliography. I thank Lt Gen Terry Gabreski (USAF, retired), Dick Hillestad, and Louis (Kip) Miller for reviewing this document and providing suggestions for improving these reflections.

RAND research in the logistics area is a compilation of work that has integrated the development and analysis of many ideas developed by many people, and I am certain that I will miss some important contributors to the thinking outlined in these remarks. I ask them to forgive me for not mentioning them specifically and to understand how they have influenced the themes and analytic principles outlined below.

Abbreviations

A9	Studies, Analysis and Assessments
ACC	Air Combat Command
ACC/CC	air combat command/commander
ACS	agile combat support
AEF	Air and Space Expeditionary Force
AFCENT	U.S. Air Forces Central Command
AFFOR	Air Force Forces
AFIMSC	Air Force Installation and Mission Support Center
AFIT	Air Force Institute of Technology
AFLC	Air Force Logistics Command
AFLC/XR	Air Force Logistics Command, Deputy Chief of Staff for Plans and Programs
AFLMA	Air Force Logistics Management Agency
AFMC	Air Force Materiel Command
AFMC/CV	Air Force Materiel Command, Vice Commander
AFSC	Air Force Sustainment Center

AFSPC	Air Force Space Command
ALC	Air Logistics Center
ALEX	Agile Logistics Experiment
ANG	Air National Guard
AOC	Air and Space Operations Center
AOR	area of responsibility
BATCAM	Battlefield Air Targeting Camera Autonomous Micro-Air Vehicle
BCAT	Beddown Assessment Tool
C2	command and control
C2ISR	command, control, intelligence, surveillance, and reconnaissance
C3I	command, control, communications, and intelligence
CCDR	combatant commander
CIRF	centralized intermediate repair facility
CLOUT	Coupling Logistics to Operations to Meet Uncertainty and the Threat
CLS	contractor logistics support
C-MAJCOM	component major command
C-NAF	Component Numbered Air Force
COCOM	combatant command
CODE	Combat Operations in Denied Environments
COMAFFOR	Commander of Air Force Forces
CONOP	concept of operations

CONUS	continental United States
COP	common operating picture
CS	combat support
CSAF	Chief of Staff of the Air Force
CSC2	combat support command and control (sometimes combat support planning and execution)
CSCMS	Combat Support Capability Management System
CSL	CONUS support locations
C-SPEC	Combat Support Planning and Execution System
CVAF	Vice Chief of Staff of the Air Force
DoD	U.S. Department of Defense
DRIVE	Distribution and Repair in Variable Environments
EAF	Expeditionary Aerospace Force
FOL	forward operating location
FPASS	Force Protection Airfield Surveillance System
FSL	forward support location
GOSG	General Officer Steering Group
HAF	Headquarters Air Force
HQ	headquarters
JCS	Joint Chiefs of Staff
JEIM	Jet Engine Intermediate Maintenance

JFACC	Joint Force Air Component Commander
JLSC	Joint Logistics Systems Center
JTF NA	Joint Task Force Noble Anvil
LANTIRN	Low Altitude Navigation and Targeting Infrared at Night
LEA	Logistics Enterprise Analysis
LICAM	logistics implications capabilities assessment model
LMSC	Logistics Management Systems Center
LOC	Logistics Operations Center
LOGAID	Logistics Analysis to Improve Deployments
LOG C2	LOGISTICS Command and Control
LOG C3I	LOGISTICS Command, Control, Communications, and Intelligence
MAJCOM	major command
MICS	Management Information and Control System
MIS	Management Information System
NATO	North Atlantic Treaty Organization
OAF	Operation Allied Force
OEF	Operation Enduring Freedom
OIF	Operation Iraqi Freedom
OO-ALC	Ogden Air Logistics Complex
OPLAN	operation plan

OSD	Office of the Secretary of Defense
PACAF	Pacific Air Forces
PAF	RAND Project AIR FORCE
POM	program objective memorandum
PPBES	planning, programming, budgeting, and execution system
RAF	Reaction Air Force
RBMS	Readiness-Based Maintenance System
RCC	Readiness Control Center
RDB	Requirements Data Bank
ROBOT	RAND Overseas Basing Optimization Tool
ROC	required operational capability
SES	Senior Executive Service
SECDEF	Secretary of Defense
SM-ALC/CC	Commander, Sacramento Air Logistics Center
SPO	System Program Office
START	Strategic Tool for the Analysis of Required Transportation
TAB-ROM	Theater Air Base Resiliency Optimization Model
TAB-VAM	Theater Air Base Vulnerability Assessment Model
UAV	unmanned aerial vehicle
UCAV	unmanned combat aerial vehicle
USAF	U.S. Air Force

USAFE	U.S. Air Forces in Europe
USFK	United States Forces, Korea
VAS	VISION Assessment System
VISION	Visibility of Support Options
WRM	war reserve materiel
WSMIS	Weapon System Management Information System

Introduction

In an exchange of emails in late 2017 with Michael Rich, General James P. Mullins (U.S. Air Force [USAF], retired), former commander of Air Force Logistics Command, indicated how much he valued RAND's contributions to Air Force logistics thinking and how that thinking had led to improvements in weapon system readiness. Michael shared that correspondence with several current and former senior leaders at RAND, including Don Rice, Jim Thomson, Ted Harshberger, Andy Hoehn, and others, and copied me. Having worked with General Mullins during the last eight years of his Air Force career, I took the opportunity to write to him to indicate that the vision for the logistics system that he outlined around 40 years ago still serves as a guidepost in formulating significant portions of our RAND research agenda to this day. Based on this exchange and knowing of the close relationship that RAND shared with General Mullins, I was asked to discuss my reflections of how RAND has interacted with the Air Force over the last 40 years to inform decisions involving logistics planning, programming, and budgeting.

In my remarks below, I draw attention to some of RAND's key logistics system thought leaders and outline their contributions to how one might think about designing and evolving the Air Force logistics posture to meet operational needs in wartime environments fraught with uncertainty. Within the Air Force, I draw attention to the role that General Mullins served in outlining a vision for Air Force logistics and how to approach logistics system analysis. I also point out, as General Mullins recognized, that progress in improving the logistics

system is seldom measured in giant leaps forward but, rather, as one would “eat an elephant”: one bite at a time. General Mullins indicated that, lacking the glamour and excitement of the war machine’s moving parts (its end items), logistics must fight every step of the way, first for recognition and then for parity in the ongoing battle for limited resources—a battle that must be successfully fought and is unending. Hence, the need to continuously fight the battle for logistics resources with objective analyses. Over the years, several enduring themes have evolved that are useful in formulating objective logistics analyses. In the course of these remarks, I point out how various senior leaders in the Air Force have picked up these themes following General Mullins’ retirement and continued the push to make the Air Force logistics system responsive and adaptable to meet changing operational needs. The intent of this report is to show how RAND has worked very closely with the Air Force leadership to develop, maintain, and evolve an approach for improving the Air Force logistics system. These reflections highlight some of the enduring themes that many of us in RAND logistics research have pursued over many decades to help shape logistics analyses. These enduring themes are still relevant for framing current and future logistics research. However, these important themes have not always been given adequate attention. At times, external and internal thought leaders drove attention to other topics and issues. In such situations, it has fallen to researchers at RAND to serve as a keeper of the “corporate memory” of how to design logistics systems that can enable combat operations in a world filled with uncertainty. By retaining deep knowledge and expertise in logistics and in the overarching themes that have guided RAND’s logistics research for the Air Force over the past 40 years, RAND researchers can be ready to engage on these key themes and enduring questions over the long term. In presenting these themes, I discuss how they evolved over time. I also provide my view of important external events that have driven Air Force interests in various time periods and the ways in which RAND has addressed these interests.

Prologue: Some Ideas That Shaped My Early Thinking About Air Force Logistics and Prepared Me to Act Given the Opportunity

Some of my thinking about Air Force logistics and the appreciation that I have for the enduring themes that guided this thinking were shaped very early in my career and would remain with me throughout my career. My association with RAND has allowed me to pursue and advance these themes and work with many thought leaders at RAND when I was an officer in the Air Force and after I retired. I am still working to sharpen these themes and incorporate them as appropriate in current research efforts.

The first theme concerned the relationship of logistics to combat operations. When I was a new second lieutenant assigned to Air Force Systems Command's Electronics Systems Center in Bedford, Massachusetts, I worked for two "old" operators. Soon after I arrived, they indicated that, to them, the Air Force was all about combat operations and that, if I were to have a career in the Air Force, I would need to understand how air power could be employed. They promptly sent me to Air University to attend the weapons employment course so that I would know something about how combat operations are planned and executed. This experience stayed with me for a lifetime. As a result, most of the logistics research that I have led over the years has been oriented to determine how logistics options impact *the effectiveness of combat power* and the costs for achieving these increments of effectiveness.

The second theme concerns the importance of taking a systems approach to understanding logistics. After serving two years at Electronics Systems Center, I was selected by the Air Force to attend the University of Minnesota, where I earned a Ph.D. in business administration. As part of my studies, I gained an appreciation for a systems approach to logistics research and where quantitative analysis techniques could be used to shed light on important problems. I was also fortunate to have studied economics, which enabled me to understand how many logistics problems could be viewed as a set of system alternatives that dealt with understanding how the allocation of scarce resources impact combat effectiveness—a key concept that has guided a great deal of RAND logistics research.

While the first two themes helped me identify areas of knowledge I wanted to pursue, the third reminded me that acquiring a useful way of thinking was as or more important than the specific pieces of knowledge I would pick up along the way. After I received my Ph.D., Lt Col Chuck Doryland, a colleague and mentor of mine at the Air Force Institute of Technology (AFIT) and an F-4 reconnaissance pilot in Vietnam, really helped me learn how to think. He and I became engaged in very high-visibility research in which we would leverage student theses to affect U.S. Department of Defense (DoD) logistics policies. During this time, I never once asked Chuck a question without him asking me another in return. From these exchanges, I learned to make judgments, to continually question what we were doing, and—in situations where the truth of a problem could never be fully known—to be humble about how much light we could shed on real problems. I also learned that if I was sincere in what I was doing, and if I knew my limitations, then others around me would help me understand more of the problem. And, if I was wrong in my assessments, well, the “system” would be strong enough and as flexible as a rubber band to snap me back on track.

Also, after leaving AFIT, I was assigned to Air Force Logistics Command, and Colonel Jack Abell was my supervisor. Jack was a RAND fellow in his Air Force career and introduced me to several people at RAND who would help me continue to learn about how to think about logistics problems. Jack introduced me to Irv Cohen and

Hy Shulman, two important logistics thought leaders at RAND, who would take me under their wings and be my mentors for as long as they lived. They always challenged my thinking. They continuously asked whether the problem formulation was correct and whether the methods and data were adequate to shed light on important problems. Interactions with them taught me the RAND way of conducting research, how to form and leverage the skills of multidisciplinary research teams, how to test research hypotheses, and to be humble in every research undertaking.

Finally, the fourth theme deals with ensuring that uncertainty receives adequate attention in our logistics analyses. This theme has been the topic of interest and intense conversation at RAND since its very beginning. I give credit to Irv Cohen,¹ one of my lifelong mentors, as mentioned above, who led logistics analyses at RAND Project AIR FORCE (PAF) for more than 30 years, for raising the importance of incorporating uncertainty in logistics research and getting me and others at RAND to pay attention to it. Irv thought that RAND logistics research had placed too much attention on attempting to *predict* logistics demands and to improve the ability of logistics processes to supply these demands. While Irv understood that predictions must be made to provide the resources needed to shape logistics postures, he thought that too little attention was being given to designing *adaptive mechanisms* within the logistics system that allow the system to respond quickly to unanticipated changes and shifts in demand—which are inevitable, given the *uncertainty* surrounding potential adversary actions and other state-of-the-world uncertainties. The need to address uncertainty is a key theme that needs to be constantly kept in the forefront of thought when analyzing the effectiveness and costs of military logistics options.

I will return to each of these themes over the course of these remarks.

¹ In this document, I mention many RAND researchers by name and indicate how their work influenced my thinking and the direction of my research over the years. The annotated bibliography is organized by author, and the interested reader can find references to the documented work of those who influenced my thinking and how they might state the issues that we were confronting during various time periods.

1976 to 1979: Understanding How Logistics Policies, Processes, and Postures Impact Operationally Relevant Metrics, Costs, and Risks

I begin these reflections in 1976, when I was first assigned to Air Force Logistics Command (AFLC) as an analyst in the Studies and Analysis Directorate (XRS) within the office of the Deputy Chief of Staff for Plans and Programs (XR). At that time, then-Brig Gen Mullins was the Deputy Chief of Staff for Plans and Programs at AFLC. During this assignment, Brig Gen Mullins focused the command's attention on how well AFLC could meet its wartime responsibilities, when flying activity is intense and demands for resources are most critical. Brig Gen Mullins placed an emphasis on determining how proactive analysis of AFLC mission performance could be expected to impact potential wartime operational effectiveness. This approach was a distinct departure from the previous Air Force operational planning practice, in which AFLC capabilities were assumed to be adequate to meet needs specified in operational plans. Thus, AFLC capabilities and constraints were not directly included in wartime operational planning activities, and combatant commanders were, therefore, planning operations that may not have been supportable from a worldwide logistics viewpoint. The new focus required AFLC to understand current war plans and to determine how AFLC resource levels and process performances could be expected to impact wartime operational capabilities, a shift in emphasis that had a profound impact on the command. The shift was reflected in changes to AFLC's organization: The Deputy Chief of Staff for Plans and Programs (AFLC/XR) was reorganized to have

a Requirements and Capabilities Directorate, which would determine AFLC requirements for meeting wartime taskings and the command's capabilities to meet those wartime taskings; a Programing Directorate, which would close the gap between wartime requirements and the AFLC capabilities to meet them; and a Studies and Analysis Directorate, which would develop enhanced techniques to evaluate materiel requirements and explore the effectiveness and costs of AFLC options for accomplishing the AFLC mission sets.

AFLC took an expeditionary and aggressive role in positioning programmed depot maintenance facilities in Europe and the Pacific to avoid moving weapon systems and heavy end items, such as engines, back to continental United States (CONUS) depots to service the systems stationed outside CONUS. Royal Air Force Base Kimble was created as a centralized intermediate repair facility (CIRF) to support A-10s on the European continent and included a European distribution system, which had been recommended in PAF analyses led by Mort Berman and others. We will return to these CIRF studies later. Also, AFLC Detachment was located at Kadena Air Base on Okinawa to service Air Force aircraft engine overhauls, spare parts maintenance, and other actions for aircraft stationed on the Korean Peninsula.

During 1976 and 1977, I reported to Colonel Jack Abell, chief of the AFLC Studies and Analysis Directorate, who, as mentioned earlier, had been an Air Force fellow at RAND. After Jack's retirement, he would later join RAND as a logistics analyst, where we would work together for many years. At the time, the Studies and Analysis Directorate was focused on predicting spare parts, engine, and other materiel requirements needed to meet demands both within AFLC repair depots and at Air Force bases where demands were generated from training operations and exercises. A major objective was to develop cost-effective inventory management policies, which was defined as the fewest backorders per dollar invested in inventory for items within a specified stratification, such as for items used on F-15s. Within AFLC, attention was given to computing variable safety levels for peacetime operating stocks, which discriminated against expensive stock items in order to achieve the fewest backorders per dollar invested in spare parts within given item stratifications. Spare parts support for war-

time operations was provided by an AFLC War Readiness Spares Kit (WRSK) computation system called D029, which was programmed to minimize the sum of aircraft downtime and the expected number of backorders in each aircraft. The aim was to predict required wartime aircraft stock levels needed to achieve a specified level of support for each weapon system for a designated period of time.

At RAND, in the late 1960s, Craig Sherbrooke had developed METRIC (Multi-Echelon Technique for Recoverable Item Control), a mathematical technique for forecasting peacetime demands for spare parts and determining optimal inventory levels at the base and the depot. METRIC was designed for application at the weapon-system level, and its primary aim was to minimize backorders associated with individual weapon systems for specified levels of reparable spares investments associated with each weapon system at the base and depot levels. METRIC was the first multi-echelon, multi-item model ever proposed for Air Force implementation.

During this time, Jack Muckstadt developed a variation of METRIC known as MOD-METRIC to improve the jet engine requirements determination process. Jack was an Air Force Reserve Officer at the time assigned to the AFLC Studies and Analysis Directorate. Jack and I worked together on various LOGAIR options analysis (LOGAIR was a dedicated contract air service that connected AFLC Air Logistics Centers with each other and with major continental U.S. Air Force bases). His work helped shift attention from backorders collected by weapon system to determine how engine modules and selected components would impact engine availability.

At the Logistics Management Institute (LMI), T. J. O'Malley, Randy King, and Mike Slay were working on modifications to METRIC that shifted the focus from minimizing backorders for specified categories of items within a weapon system to maximizing aircraft availability for various increments of investment in spare parts and in repair dollars to fix unserviceable spares. The LMI modifications to the METRIC model were called the Aircraft Availability Model and allowed the Air Force to focus attention on how alternative investments in spares inventory impacted projected weapon system performance (aircraft availability) in future time periods. The approach

subsequently became the backbone of the AFLC reparable spare parts inventory computation process.

I followed these developments while being primarily engaged in evaluating how alternative logistics designs would improve weapon system readiness. Soon after arriving at AFLC, Colonel Abell encouraged my interaction with RAND to hone my skills as a logistics analyst. The first meeting with RAND analysts was not easy—but was inspirational nonetheless—as Irv Cohen, Hy Shulman, Tom Lippiatt, Dick Hillestad, Manuel Carrillo, Ray Pyles, and others critiqued the formulation of how I proposed to evaluate the LOGAIR system and how various LOGAIR routing alternatives and corresponding transportation times would likely impact weapon system readiness. Despite these critiques—or perhaps because of them—this first meeting captured my attention and led to my lifelong relationship with RAND.

These meetings and the ongoing dialogue they inspired were important in the process of determining how to relate logistics resources to operationally relevant metrics—e.g., weapon system availability or sortie generation capability. I continued to focus on this issue after being assigned in 1977 to the Requirements and Capabilities Directorate, AFLC/XRP, where I was asked to head up the Readiness Assessment Branch. Shortly afterward, Maj Gen Mullins left Headquarters AFLC to become commander of Ogden Air Logistics Center, and Maj Gen Leo Marquez succeeded Maj Gen Mullins as the AFLC/XR. In my new position, I focused on developing tools and techniques to assess AFLC readiness to support wartime activities.

During this time, work was initiated at RAND by Steve Drezner, Tom Lippiatt, Dick Hillestad, Mort Berman, Irv Cohen, Hy Shulman, and others to evaluate how the use of CIRFs affected operational effectiveness and costs in wartime environments. I became the point of contact for AFLC engagement in these analyses. The focus on wartime environments prompted Steve Drezner, Dick Hillestad, Gordon Crawford, and others to develop Dyna-METRIC (Dynamic Multi-Echelon Technique for Recoverable Item Control). Dyna-METRIC added dynamic scenarios to the steady-state approach of the Aircraft Availability Model to evaluate how changing wartime demands would affect logistics resourcing and process performances. The tool was used

to evaluate the effects of support alternatives (i.e., various spare parts levels and repair process performances) on projected aircraft sortie generation rates. Dyna-METRIC, which was updated several times, would later become a key analytic tool used to support much of RAND's work in spares and repair management in the 1970s and 1980s.

During this period, I participated in the development, testing, and use of Dyna-METRIC in RAND-led analyses of centralized in-theater repair working with Ray Pyles, Dick Hillestad, Irv Cohen, and others. My participation in the CIRF studies was supported by the commander of AFLC at the time, General Bryce Poe, and I briefed the impacts of the CIRF analyses to the AFLC command section, the joint logistics commanders, and other groups. The Air Force ultimately adopted the use of wartime CIRFs in the air war over Serbia, as I will discuss later.

1979 to 1982: Integrating Logistics Capabilities and Constraints Within Wartime Planning and Readiness Assessments

In 1979, Maj Gen Mullins, then the commander of Ogden Air Logistics Center (OO-ALC), conceived of the idea of building a Readiness Control Center (RCC) with conference rooms, computational and display capabilities, and a population of operations research and logistics analysts who would assess F-4 and F-16 readiness to meet their wartime taskings. At the time, OO-ALC was responsible for sustaining F-4 and F-16 weapon system readiness. RCC personnel would work to identify AFLC resources and processes that would prevent the F-4 and F-16 from meeting these wartime requirements. Before General Mullins left OO-ALC to take command of 15th Air Force, as a Lt Gen, he arranged for Colonel Tom Collipi and me to be assigned to the Materiel Management Directorate at OO-ALC, where I assisted Colonel Collipi in creating the RCC. Maj Gen John Murphy succeeded General Mullins as the OO-ALC commander and followed through with the creation of the RCC. At the RCC, I worked with others to create and lead an organization of 12 analysts and computer programmers. We worked with the F-16 system support manager to obtain a dedicated computer to use in assessing the readiness of F-4s and F-16s to meet war plan taskings. A major section of a building was set aside for the RCC.

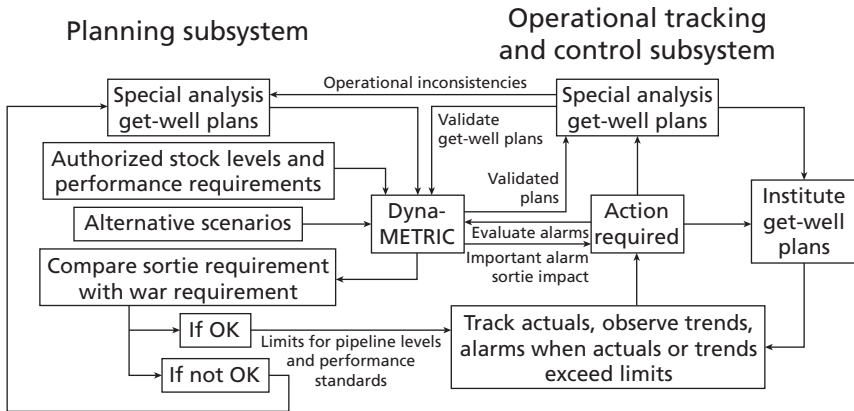
This was a period of close collaboration between the Air Force and RAND as well as the integration of RAND-developed tools into Air Force logistics systems. In 1981, Maj Gen Marquez became the

commander of OO-ALC after Lt Gen Murphy was promoted and left OO-ALC to become the 15th Air Force commander. Lt Gen Mullins was promoted to general and became AFLC commander. Maj Gen Marquez supported the RCC initiatives, one of which involved working with RAND researchers, including Dick Hillestad, Manuel Carrillo, Ray Pyles, Irv Cohen, Pat Boren, Hy Shulman, and others, to install a copy of Dyna-METRIC on the RCC computer system. The RCC team developed data interfaces and output reporting forms to automatically assess the readiness of F-4s and F-16s to meet wartime taskings given on-hand repairable spares and engines using Dyna-METRIC as the analytic engine.

These routine wartime assessments began with the F-4. Analysis of F-4 wartime support effectiveness had been part of the RAND Pacific Air Forces (PACAF) Concept and Design of the Combat Support Capability Management System (CSCMS) project, which was led by Irv Cohen and Ray Pyles. At the time, the commander of Pacific Air Forces was concerned about the lack of serviceable F-4 engines and spare parts and asked RAND to examine the situation. Because of our close relationship, Irv and Ray asked me to support that analysis, and with Colonel Collipi's approval, I led the development of the CSCMS planning subsystem, using assigned RCC analysts, as shown on the left side of Figure 4.1. Ray Pyles led the development of the operational tracking and execution subsystem, which is shown on the right side of Figure 4.1.

One of the unique features of the CSCMS included using a model, Dyna-METRIC, to translate how logistics resource levels and process performances impact operationally relevant metrics projected into a contingency environment sometime in the future. In this case, expected demands for F-4 spare parts and engines were projected over a wartime horizon along with the expected resupply for failed items, which could meet demands by using serviceable stock or by having items resupplied from maintenance at the base or depot levels, which included transport times between the base and depot, where necessary. The model determined whether the wartime-required sorties could be generated given existing on-hand spare parts and, if not, identified how these spares shortfalls would impact the expected number of

Figure 4.1
Improved Logistics Planning, Execution, Monitoring, and Control Processes
Identified in the PACAF Combat Support Capability Management System



grounded aircraft and sortie generation requirements that could not be met because of a lack of spare parts or spare engines. The intent was to inform operational planners about which aircraft would likely not be available day by day over the course of the wartime horizon and to alert AFLC item managers and repair process managers which spare parts needed attention to meet wartime requirements.

Another unique feature of this construct was that the planning system could establish control limits on the specific logistics processes needed to produce a desired aircraft availability rate or number of serviceable aircraft over a specified time horizon. The operational tracking and control subsystem would then monitor these control limits—e.g., repair times or transport times—to see whether the system was performing as planned. If a control limit was exceeded, the person responsible for maintaining performance would be notified of the need to take corrective action to get the system back within control limits. In this example, the closed-loop performance feedback system acts to keep repair times and transportation delivery times within a specified set of limits, much as a thermostat works to control the temperature within a room within specified limits.

The CSCMS project pushed the development of Dyna-METRIC. The project also outlined some important concepts that would be cited years later, when RAND research attention was again focused on improving overall Air Force planning, execution, monitoring, and control processes across the planning, programming, budgeting, and execution system (PPBES) by explicitly relating how logistics capabilities and constraints impact operationally relevant metrics. The results of the PACAF CSCMS project were widely briefed to senior Air Force leaders, including General Creech, commander of Tactical Air Command, and Maj Gen Larry Welch, Tactical Air Command, Deputy Chief of Staff for Operations at the time. General Welch would later become the Air Force Chief of Staff and would be instrumental in implementing the CSCMS planning subsystem concepts as part of a worldwide Air Force readiness assessment system.

Over time, the RCC became a showcase for proactive AFLC wartime assessments. When General Mullins returned to AFLC as the commander, the OO-ALC leadership established regular reporting schedules in which the F-4 and F-16 weapon system support managers would brief General Mullins and AFLC headquarters (HQ) on the readiness of their systems to meet wartime taskings. A stop at the RCC for current readiness assessments was also included on the agenda for visiting generals, DoD personnel, and congressional representatives.

During this time, Ray Pyles and I wrote a Note entitled *Measuring and Managing Readiness: The Concept and Design of the Combat Support Capability Management System* (Pyles and Tripp, 1982), which outlined how readiness assessments of weapon systems should be conducted and which answered, in part, the perennial question: ready to do what, which in this case meant how ready the weapon system was to meet its wartime taskings in a specific contingency operation. These enhanced planning, execution, monitoring, and control processes were recognized as being important to improving command and control (C2) awareness of LOGISTICS capabilities and constraints and translating them into operationally relevant metrics.¹ Because planning,

¹ Most of the publications in the annotated bibliography try to make the point that combat support (what I refer to as *LOGISTICS* in this publication) contingency planning, execution,

execution, monitoring and control processes are so important to operational planning in the near term and in command and control of logistics resources and processes, the near-term applications of the Pyles and Tripp concept have often been referred to as important parts of LOG C2 concepts. Over the years, RAND researchers have addressed how to incorporate these concepts into near-term contingency planning efforts and integrate them into improving the joint and Air Force C2 enterprise. In addition, these enhanced logistics planning, execution, monitoring, and control processes need to be applied over the entire PPBES time horizon to recognize how logistics capabilities and constraints impact operationally relevant metrics over all time frames. I will discuss these ideas in more detail below.

As a practical matter, while I was assigned to the OO-ALC RCC, the planning subsystem received much more attention than the operational tracking and control system. The RCC used Dyna-METRIC to determine how the availability of on-hand spare parts would impact sortie generation capabilities for F-4s and F-16s in important PACAF and USAFE contingency scenarios. The version of Dyna-METRIC that was used in these assessments did not explicitly model maintenance or transportation capabilities and constraints. These capabilities would be added to later versions of Dyna-METRIC but were never included in AFLC weapon system readiness assessments. Instead, repair times and transportation times for each item were assumed to take the average time for these activities for each item addressed in the analyses. The planning subsystem analyses identified problem items that were forecast to limit sortie generation capability, and item man-

monitoring, and control processes need to be enhanced to support the global operational planning, execution, monitoring, and control processes (or *operational C2*). In other words, the LOGISTICS processes that I discuss need enhancement and should be embedded within the operational planning, execution, monitoring, and control processes. The term *CSC2* (or *LOG C2*) has been used as shorthand language to describe these enhanced LOGISTICS planning, execution, monitoring, and control processes, which should be considered as part of an enhanced operational planning, execution, monitoring, and control process rather than an end to themselves. In other words, these enhanced processes must be incorporated within the operational planning, execution, monitoring, and control processes for them to be effective.

agers had to brief their “Get Well” plans for items that prevented the attainment of sortie generation goals.

There were many reasons why the operational tracking and control subsystem did not receive as much attention as the planning subsystem. There were problems in collecting the needed data, and the data were “noisy,” with threshold alarms crossed frequently and data volatility needing more attention. The intent of the monitoring and tracking subsystem was to notice significant deviations from the plan and then to get the appropriate people in the system to make responsive adaptations to correct poorly performing portions of the system when needed. The planning subsystem, which only addressed whether there were enough on-hand spares to meet wartime sortie generation requirements, was further developed and ultimately became part of routine weapon system readiness assessments against war plans, as incorporated in the Weapon System Management Information System (WSMIS). The intent was to include how maintenance and transportation constrained performance, but this never occurred, in part due to the modeling complexity of including these constraints and the time it took to develop these modeling capabilities.

1982 to 1985: Developing Proactive Weapon System Readiness Assessments, LOG C2 Concepts, and Efforts to Address Uncertainty in Logistics System Designs

As noted earlier, General Mullins was promoted to general and took command of AFLC in 1981. In 1982, I was reassigned to HQ AFLC in the Special Projects Office located in the office of the Deputy Chief of Staff for Plans and Programs and was promoted to lieutenant colonel. This office was led by Col Jim Hopp (later to be a major general and commander of the AFLC Logistics Management Systems Center (LMSC) and Sacramento Air Logistics Center (SM-ALC/CC)). The Special Projects Office was created as a place to incubate and test out General Mullins' focus areas and to develop command-wide implementation efforts. Some of the notable efforts defined, developed, and/or tested through this office included the Command Meaningful Measures of Merit Program; the Logistics Command, Control, Communications, and Intelligence (LOG C3I) Program; and the early development of WSMIS to assess the readiness of all AFLC-managed weapon systems. For my first year or so back at HQ AFLC, I worked to expand WSMIS and develop the LOG C3I Required Operational Capability (ROC) Statement.

A key development during this period was the creation of the AFLC Logistics Operations Center (LOC), which was stood up by General Mullins in 1982–1983 and designated as the central organization within AFLC to conduct routine weapon system readiness assessments to determine whether AFLC resource levels and process

performances were adequate to meet wartime weapon system support requirements. The Logistics Management Systems Center was also stood up to focus on development of AFLC management information systems, including materiel inventory requirements systems, distribution management systems, engineering management systems, depot maintenance management systems, and others.

This period also saw implementation of logistics concepts developed by RAND and the Air Force. Soon after I arrived back at HQ AFLC, General Mullins and I visited Vern Orr, Secretary of the Air Force, to obtain out-of-cycle funding for the initial development of WSMIS, which was granted. As mentioned earlier, WSMIS was a central vehicle for implementing the enhanced logistics planning, execution, monitoring, and control system concepts that Ray Pyles and I outlined in the PACAF CSCMS Note. WSMIS would be one of the LOC's primary analytic systems to support routine weapon system readiness against established war plans. With out-of-cycle funding secured, I worked to have WSMIS contracted out for development by Dynamics Research Corporation, which would take Dyna-METRIC and further develop automated information feeds from war plans and other data systems that could be used to conduct readiness assessments on a periodic basis.

In this period, General Welch, Air Force Vice Chief of Staff (CVAF), was extremely interested in having routine readiness assessments to alert wing commanders and senior leaders to limiting factors that would lower weapon system availability. He asked me to come to the Pentagon for a personal discussion on the WSMIS efforts. As background, in the early 1980s, President Reagan had obtained large increases in the defense budget, with some of this money earmarked to ensure the readiness and sustainability of existing weapon systems. General Welch was concerned because some wing commanders were indicating that their units were not "ready" to go to war as reported in the mandatory unit-level readiness reporting system even after the Reagan infusion of money into readiness and sustainment efforts. The Vice Chief was interested in having some analytic rigor behind individual unit readiness reporting. He was familiar with the AFLC thrust of evaluating *theater-wide readiness to meet war plan requirements* and

wanted a unit-level assessment system to measure readiness against unit-designated operational capabilities. During the session with the Vice Chief, he asked when routine unit-level assessments could be developed in WSMIS for use by wing commanders in their mandatory unit-level readiness reporting. I promised that we could do this for several major systems within six months.

When I returned to AFLC, I briefed General Mullins and others on the discussions, and they supported the efforts to accelerate WSMIS developments, including these unit-level readiness assessments. The Vice Chief visited AFLC several times in 1982 and 1983 to check on WSMIS progress. WSMIS made initial assessments as promised and became a central tool to support not only the LOC in its theater-wide war plan assessment mission, but also unit-level assessments. The latter were incorporated in a unit-level readiness assessment system, which required each operational unit to report its ability to meet war-time sortie generation requirements, as determined by WSMIS Dyna-METRIC unit-level assessments.

At RAND during this period, Dick Hillestad, Karen Isaacson, and Manuel Carrillo continued to develop and refine Dyna-METRIC, adding enhancements and capabilities, including the ability to assess how maintenance queues affect sortie generation. Ray Pyles and others developed reports on how to use Dyna-METRIC and held several seminars on Dyna-METRIC uses, characteristics, and limitations. Various Dyna-METRIC versions used to support WSMIS were placed under configuration control by a WSMIS Dyna-METRIC users' group. A continuing education class was created at AFIT to train many in the logistics assessment community about WSMIS capabilities and uses. RAND enhancements to Dyna-METRIC included modeling to incorporate selected types of maintenance processes—e.g., continuous flow processes, job shop processes. The idea was to determine how maintenance process queues and adaptations might impact operational sortie generation capabilities. This modeling added complexity to the Dyna-METRIC analytic framework, including simulation subsystems

to model maintenance process queues and their impacts on sortie generation capability.¹

In 1983, WSMIS, now designated an official AFLC information system (D087), was transferred to the AFLC Logistics Management Systems Center, and I was selected as the WSMIS System Program Office (SPO) director. The cadre of staff formed in the XR special projects office to oversee initial WSMIS development efforts were transferred with me to form the basis of the WSMIS SPO. WSMIS grew in capabilities and was installed on the HQ AFLC World Wide Military Command and Control System computers and supported by contractor personnel. The principal customers for WSMIS products were the LOC, weapon system sustainment managers, and unit-level commanders.

I served as SPO director from 1983 to 1985. During this time, WSMIS was fielded, documented, and used to evaluate theater-level assessments. Unit-level assessments were also conducted, including WSMIS unit assessments. To this day, the Air Force unit-level readiness reporting system contains WSMIS-forecasted sortie generation capability based on war readiness spares kit asset quantities that are on hand and serviceable. Another module was developed to track the status of the get well plans that were required for each of the items that were limiting sortie generation capability below a specific threshold. The WSMIS Get-Well Module embedded some of the concepts of the execution, monitoring, and control subsystem that Ray Pyles and I outlined in our 1982 RAND Note.

During this period, I also continued to work with Irv Cohen, Hy Shulman, and Michael Rich to flesh out the LOG C3I System Required Operational Capability document and presented briefings to senior leaders to support establishing a program to develop an AFLC LOG C3I system. I also wrote several papers that were published describing the need for LOG C3I capabilities (Tripp and Rainey, 1983; Tripp and Rainey, 1986b; Tripp, 1987).

¹ The Dyna-METRIC closed form versions—i.e., mathematically solved sets of equations—were much faster to execute on computer systems and were not as detailed as the versions that included simulations of various types of maintenance processes.

Before and during this time, I became fascinated with the cybernetic literature, and I published some academic papers and *Air Force Journal of Logistics* articles that included cybernetic concepts to explain how the LOG C3I system needed sensors to detect how well AFLC processes were supporting wartime objectives and that “the planning and assessment processes of the AFLC LOG C3I system were the brain function” of the institution that could direct “the arms and legs of the institution which were the maintenance, distribution, procurement, and other functions” (Tripp and Rainey, 1983; Tripp and Rainey, 1986b; Tripp, 1987). Feedback systems would detect significant deviations from planned performance that needed to be corrected if planned sortie production were to be achieved.

Toward the end of this period, some began to voice philosophical issues about the whether the emphasis on readiness assessments depended too much on the ability to predict outcomes in an uncertain world. In the years that followed, Irv Cohen questioned whether I and others in the Air Force had paid sufficient attention to the execution, monitoring, and control system aspects of the system design. These discussions became more spirited as Irv and others became deeply engaged in the Uncertainty Project—i.e., understanding how the logistics system could be made more adaptive to uncertainties in demand and supply. The Uncertainty Project focused on how to design responsiveness into the logistics system—i.e., provide repair and transportation capabilities that could respond to demands when needed responsively. During most of this period, I was fully occupied on implementing the planning assessment system as part of Air Force and AFLC wartime assessment systems and was viewed at times as supporting the “prediction” school of thought. From my view, I appreciated the need to develop logistics systems that could respond to unanticipated events rapidly, but I was fully occupied with implementing WSMIS and enhancing the official Air Force readiness reporting systems.

Irv Cohen was concerned that the work on responsiveness was not being given enough attention internally and externally and would keep pressure on research staff to think more about designing responsive logistics systems, and, as a result, he would engage the staff and Air Force logistics leaders with frequent debates about whether the

“prediction” view was dominating research within the Air Force and “responsiveness” thinking was not given enough attention. This debate is captured in Hodges’s work *Onward Through the Fog* (Hodges, 1990). Ultimately, the RAND position on the issue—documented in the *Coupling Logistics to Operations to Meet Uncertainty and The Threat (CLOUT)* (Cohen, Abell, and Lippiatt, 1991) and Hodges reports and supported by Irv, me, Pyles, Abell, and others—was that uncertainty is inevitable, and, while predictions must be made across the PPBES, logistics planning should include “hedging strategies” by investing in single-purpose assets (e.g., spare parts) at prudent levels and then investing to the maximum extent possible in multi-use assets and processes (e.g., C2 capabilities, distribution capabilities, repair capabilities) that can adapt rapidly to changes as they occur.

From my view, this debate still needs attention within the Air Force and is particularly relevant in designing logistics systems where confrontations with near-peer potential adversaries who can inflict significant damage on U.S. land-based air forces must be considered. We will return to this issue later in this set of reflections.

1985 to 1987: Implementing RAND Contributions to Readiness Assessments and Increasing Emphasis on Incorporating Uncertainty in Logistics Systems

In 1984, General Mullins retired from the Air Force and General O’Laughlin took command of AFLC and continued the directions set out for the command by General Mullins. In part because of the success of WSMIS, I was promoted to colonel in 1984 and assigned to be the Requirements Data Bank (RDB) SPO director in the AFLC LMSC. During this period, Maj Gen Jim Hopp, who I worked for in the AFLC Special Projects Office started by General Mullins, would become commander of the AFLC LMSC. RDB was the flagship program in the LMSC portfolio. The goal of RDB, later to be designated as D200, was to modernize most of the AFLC inventory requirements determination systems—e.g., D041, D039, D165, and several more—within a modern computer environment. When I was reassigned to the RDB SPO, further development of WSMIS was assumed by Virginia Williamson, who became the WSMIS SPO director. She continued development of WSMIS on the path that General Mullins and I put in place.

During this time, at RAND, Cohen, Lippiatt, Abell, and others were continuing their efforts to bring much more attention to how to design responsiveness into logistics systems designs so that, when unanticipated demands occurred, the system could adapt and respond to these demands quickly. Isaacson and Boren developed and documented Dyna-METRIC version 6, which included the ability to model

the effects of repair capacity limitations on operational effectiveness. The idea was to identify the impacts of capacity constraints and then to develop mitigation options to relieve the constraints. However, this version of Dyna-METRIC was never incorporated within WSMIS due to the difficulty of modeling specific repairable processes and identifying constraints that could be reported and evaluated in a readiness assessment system.

While serving as RDB program director, I transferred development responsibilities of D029, the wartime readiness spares kit computation system, from the RDB (D200) development program to the WSMIS (D087) SPO under the rationale that this was a wartime system—it was computing requirements to meet wartime objectives. This move would turn out to be fortuitous when, a few years later, development of RDB and other service “business systems” would be curtailed in an—ultimately unsuccessful—attempt to develop Joint Logistics Systems to achieve “economies” from capitalizing on common logistics information processes among the services. I discuss that effort later in this paper.

While I was RDB SPO director, the funds programmed to develop the AFLC LOG C3I system development were reallocated to RDB due to RDB schedule slippages and cost overruns. The LOG C3I program was officially dropped by AFLC, and the funds were used to support the development of information systems that were viewed to be the core AFLC mission processes, which included RDB and WSMIS.

In 1987, I retired from the Air Force and joined the faculty at the University of New Mexico. Michael Rich attended my retirement ceremony and made remarks on how I had worked with RAND for the last ten years of my career. He presented me with a plaque showing the cover of the Pyles and Tripp Note with signatures and kind words from my many RAND colleagues, many of whom I would come to know better, and work with more closely, in the coming years.

1987 to 1992: Building Responsiveness into Logistics System Designs to Cope with Uncertainty

When I was at the University of New Mexico, Irv Cohen and others asked me to join the RAND staff as a consultant. The main focus of my consultant work, from 1987 to 1989, was to develop a history of how RAND researchers dealt with uncertainty in their analyses from the beginning of RAND until the present.

I worked primarily with Irv Cohen and Hy Shulman on this effort. As I have already noted, Irv thought that too much attention was given to predictive research, while the effects of uncertainty were not given enough attention. As my longtime mentor and friend, Irv sought to broaden my education to think more about uncertainty and how to deal with it in the design of logistics systems. Irv pushed me to think about uncertainty in two different ways. First, he asked me to formally review the literature to understand how RAND research pioneers such as Bernice Brown, Gordon Crawford, and others dealt with uncertainty. This knowledge put me in an advantageous position to advise the Air Force on how to deal with state-of-the-world uncertainty in the design of logistics systems many years later. In retrospect, I think Irv had me do this work to help “set me right” from his perspective, and I am grateful for the opportunity he provided for me to acquire this rich philosophical background.

Second, Irv pushed the thinking envelope to the extreme and focused on describing what would be possible if the logistics processing time was zero. I believe Irv used these extremes to push thinking

about the realm of the possible, beyond conventional thinking and what might be considered practical at the time. He would push to get the community to think about how to design systems that could be very responsive in dealing with unanticipated demands that may well occur in combat operations against adversaries who have the ability to damage air bases. Irv and I would have many heated discussions about what was practical, what was possible, and how to proceed with research along the lines that Irv was suggesting. Despite our many debates, Irv Cohen remained one of my key mentors at RAND, and the history of how RAND researchers dealt with uncertainty formed a cornerstone of my professional experience.

The history of uncertainty work at RAND that Irv had me research was eventually picked up by Jim Hodges and is reported in *Onward Through the Fog* (Hodges, 1990). Hodges's report outlines the conflicts involved in dealing with statistical and state-of-the-world uncertainty over RAND's history. It documents how RAND thinking on the topic has swung over time from a focus on tools to improve prediction to a focus on building responsive logistics systems that can deal with state-of-the-world uncertainty that can result in conflicts with near peer adversaries.

In 1989, Steve Drezner and Mort Berman ask me to join the RAND research staff on a full-time basis to work on important issues in the Arroyo Center. The Arroyo Center was a newly formed RAND unit that would take over U.S. Army policy research, similar to the RAND Project AIR FORCE policy analysis unit for the U.S. Air Force. During this period at RAND, I worked with Berman, Tsai, Isaacson, Halliday, Folkesson, Dumond, and others in demonstrating how the Army could develop logistics systems to achieve weapon system availability objectives and be responsive to uncertain events. We documented this research in *The Concept of Operations for a U.S. Army Combat-Oriented Logistics Execution System with VISION (Visibility of Support Options)* (Tripp, Berman, and Tsai, 1990). In these new publications, we drew on some of the concepts Ray Pyles and I had developed in 1982 along with some of the thinking emanating from the CLOUT work (discussed below). Some of the ideas contained in these concepts were field tested by the Army and incorporated in

the Army Strategic Logistics Program to modernize and enhance U.S. Army information systems. Much of this work was motivated by the focus areas that General Mullins brought to AFLC many years earlier.

During this period, work to improve the responsiveness of Air Force logistics processes continued. Jack Abell and Louis Miller recognized that more aircraft could be kept flying if a means were found to give priority to certain spares slated for repair. Abell, Miller, and others developed and demonstrated the Distribution and Repair in Variable Environments (DRIVE) model, which was designed to help depot repair managers set repair and distribution priorities by measuring how the priority repair of various spare parts could impact aircraft availability. The intent was to make the depot maintenance system more responsive to demands as they occurred by developing responsive maintenance processes and replacing existing processes that relied on batching of sizeable workloads. The batching of workloads had been viewed as efficient for maintenance resource utilization but required large holdings of inventory to meet unanticipated demands. Furthermore, batch processing did not address how maintenance workloads could be modified to meet high-priority needs such as those that can occur in armed conflict. Within the Air Force, each component of the logistics system—e.g., maintenance, materiel management, distribution, and information on materiel condition—was treated as a stove-piped community. Each community would concentrate on its own performance and metrics associated with its segment of the system, possibly to the detriment of overall logistics system performance. DRIVE broke down these stovepipes and presented an integrated picture of how depot-level maintenance and distribution actions could be optimized to improve worldwide weapon system availability.

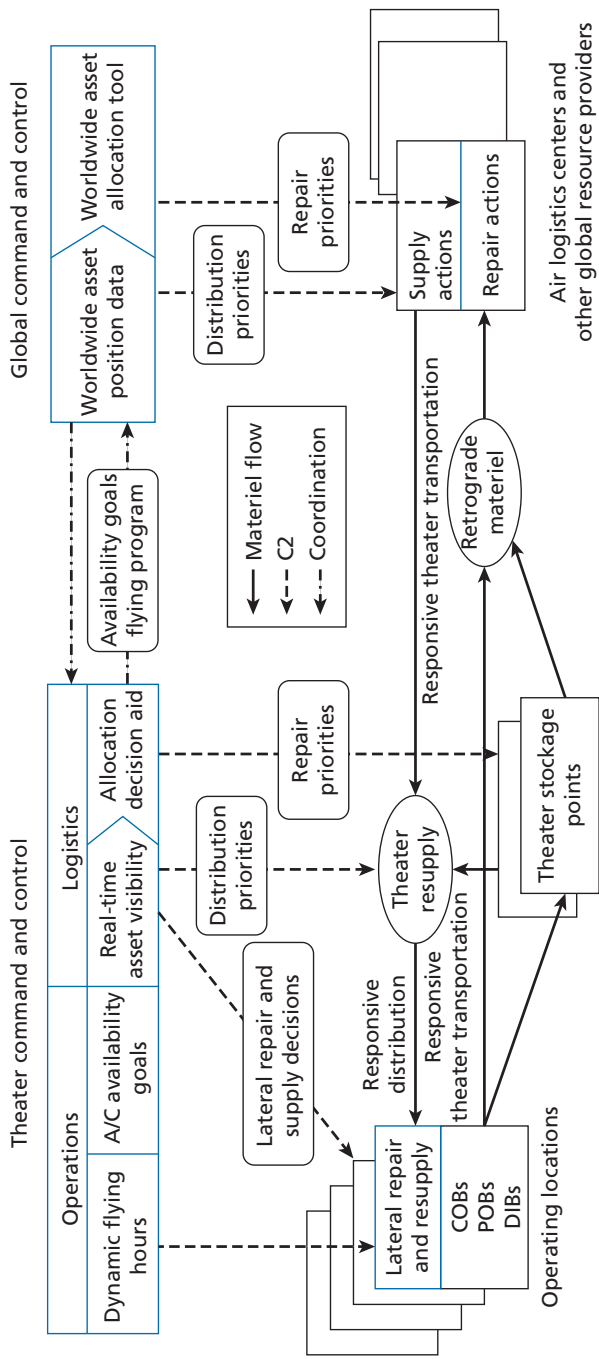
The Ogden RCC team that was conceived by General Mullins and that I was fortunate enough to form and staff back in the early 1980s worked with Abell and Miller to develop a working DRIVE prototype to show the feasibility of implementing DRIVE concepts in depot-level maintenance processes, much as WSMIS was prototyped at Ogden before it was implemented command-wide. The information system that embedded DRIVE was labeled EXPRESS by the OO-ALC prototype development team to emphasize the idea that it

would rapidly shift repair priorities and quickly bring high-priority items into the repair process and then distribute them to units that would improve aircraft availability to the greatest extent. EXPRESS is still used to this day to drive depot-level workload to maximize worldwide weapon system readiness.

During this period, Cohen, Lippiatt, and Abell published the report entitled *Coupling Logistics to Operations to Meet the Uncertainty and the Threat (CLOUT)* (Cohen, Abell, and Lippiatt, 1991). CLOUT initiatives were designed to cope with resource shortages caused by poor predictions of demand. Figure 7.1 illustrates the LOG C2 execution, monitoring, and control system processes that were described in the CLOUT report. This depiction shows features similar to the closed-loop feedback system discussed in the Pyles and Tripp planning, execution, monitoring and control system. The theater C2 system concept, illustrated on the left side of Figure 7.1, was envisioned to have near-real-time knowledge of weapon system support goals and asset information. The CLOUT concept called for an algorithm to make near-real-time allocation decisions associated with lateral supply of serviceable spares and prioritization of items that need repair within the theater. The CLOUT theater C2 execution, monitoring, and control system would also assist in making distribution system priority movement decisions to maximize theater aircraft availability objectives. This theater portion of the C2 system would be coupled with the Global C2 execution, monitoring, and control system to tie Air Logistics Center (ALC) resupply and repair actions to help meet theater needs. The CLOUT work emphasized the close linkage between operations and logistics as well as the need to orient the LOG C2 system to achieve operational objectives. CLOUT also stressed that logisticians communicate to operations in terms of how logistics resource allocation decisions impact operationally relevant metrics such as sortie generation capability or aircraft availability.

The CLOUT publication notes that the enhanced planning, execution, monitoring, and control system concepts should be applied to the planning, programming, and budget execution portion of the PPBES as well as within the execution time horizon. This idea will come up again in a later section of this paper (see Leftwich et al., 2002).

Figure 7.1
The CLOUD C2 System



1992 to 1996: A Period of Focusing on Logistics Efficiencies, with Less Attention on How Logistics Processes Impact Effectiveness

In 1992, several events occurred to lessen the attention given to how logistics processes could be designed to be more effective and responsive to unanticipated demands. First, AFLC and Air Force Systems Command were merged to form Air Force Materiel Command (AFMC). Emphasis in the command was shifted from logistics sustainment and effectiveness to acquisition process improvements. The LOC was disbanded, and routine wartime readiness assessments of how resource levels and processes would likely affect wartime weapon system sortie generation capabilities were curtailed. In 1992, the military was drawing down, and the Office of the Secretary of Defense (OSD) was also pressing to reengineer business systems to achieve greater efficiencies in supporting military operations. Information systems under the development of the AFLC LMSC were declared to be business systems instead of mission support systems, as were other services' logistics systems. The Joint Logistics Systems Center (JLSC) was created with the intention of driving efficiencies by reengineering business processes and developing modern information system applications to save money and reduce the number of personnel performing logistics services. Former LMSC systems were put on minimum sustainment funding to continue operations with current capabilities with no modernization or enhancements in capabilities. Needed enhancements were to be identified and sent to the JLSC for development in the newly envisioned "best of breed" joint system.

WSMIS was determined to be the wartime support system through decisions I made in 1985. As a result, it continued to develop capabilities during the time the JLSC was functioning, although at a curtailed level of support. WSMIS unit-level readiness assessments were still made routinely and retained in unit readiness reporting.

The JLSC concept was flawed, and, after three years, it was disbanded without any progress and several billion dollars expended. OSD recognized that the services' missions are different, and their weapons and wartime concepts of operations (CONOPs) are different; therefore, the logistics information systems need to be tailored to the specific needs of the services' goals and objectives.

At RAND, significant shifts in the research agenda were also occurring, with emphasis given to examining how the best commercial logistics practices could be applied to the Air Force and other services. However, the enduring themes that guided logistics research in the past were not entirely forgotten. The assumption from OSD was that private industry would be more efficient at delivering logistics support—a hypothesis that was not borne out. RAND initiated the Lean Logistics set of projects led by Cohen, Shulman, Pyles, Ramey, and others. This set of projects picked up themes from CLOUT and the Uncertainty Project and focused attention on building responsive, adaptive systems to respond to unanticipated events. The researchers argued that lean logistics processes capable of responding to unanticipated events would also be more efficient than the current batch processing approach to maintenance (described earlier). It was felt that this approach would be more effective in producing desired operational effectiveness—e.g., less downtime or greater sortie generation capability—by relying on “just in time” delivery of goods and services. A lesson to be derived here is that through clever formulation of project objectives, work on important themes can continue even when the external environment is not particularly favorable for furthering important concepts as recognized by our staff.

Shifts were also occurring in my own career. In 1992, I left RAND for defense industry jobs, where I would implement RAND-developed ideas, largely in the readiness assessment and LOGISTICS

command and control (LOG C2) areas.¹ I first served as Vice President of Dayton Operations for Dynamics Research Corporation and later was a senior researcher for Synergy, Inc. While at Synergy, I worked with Leftwich and George on the Logistics Analysis to Improve Deployments (LOGAID) project in support of the Air Force Research Laboratory's Armstrong Laboratory. The LOGAID effort analyzed the entire deployment process and investigated the potential for improvements through insertion of innovative technologies and processes. The LOGAID Laboratory was created as part of this effort to test concepts and release high-payoff technologies and processes to the field for implementation. I also co-led a project with Leftwich to develop a prototype Beddown Assessment Tool (BCAT) and Unit Type Code/Design and Tailoring system for Armstrong Laboratory. The BCAT effort was aimed at improving the base support planning process through the development and automation of new wing-level logistics assessment tools for use by deployment and reception planners. BCAT provided assessments of how specific logistics functional processes and inventory availability impact campaign combat objectives. This BCAT work revitalized some of the WSMIS capabilities to assess unit level readiness against wartime taskings.

Also, while at Synergy, I helped to put RAND concepts into Air Force documents and plans for implementation. I worked with Leftwich and others to determine requirements, develop concepts, and author major sections of the USAF LOG C2 CONOPs for the Air

¹ In the Air Force, *wing-level logistics* functions generally are associated with maintaining, arming, and fueling the operational systems (e.g., aircraft, unmanned aerial systems) that are employed in war or training operations. Here, *LOGISTICS* incorporates functions in both the maintenance group (e.g., maintaining, arming, fueling) and in the mission support group (e.g., civil engineering, contracting, communications, transportation, supply) at the wing level. In addition, when I refer to *LOGISTICS*, I not only discuss the functions performed at the wing or deployed unit levels but also consider how those functions need to be supported at the rear echelon organizations, which support the operational units (e.g., AFMC, United States Transportation Command, Defense Logistics Agency). When I refer to LOG C2, I discuss overall command and control of processes needed to initiate and sustain weapon system operations and base operational support needed to keep the runways, personnel shelters, food operations, medical operations, and others operational to achieve specified levels of operational performance across all echelons.

Force Deputy Chief of Staff for Logistics. I also researched requirements and authored major sections of the AFMC LOG C2 CONOPs and worked with others to author major portions of the Lean Logistics Master Plan. Our team also evaluated alternative concepts and developed approaches for monitoring Lean Logistics performance—which resulted in development and implementation of a new pipeline measurement and control system, based in part on concepts developed earlier in my research with Ray Pyles.

While this LOG C2 work was being kept alive during the period, most of the Air Force emphasis was on becoming more efficient, perhaps at the expense of effectiveness. Nonetheless, small pockets of research at RAND and in the defense industry remained closely linked and kept interested senior leaders up to date with efforts to ensure that the ideas continued to progress during a time of retrenchment from emphasis on wartime effectiveness.

1996 to 2003: Relating Logistics Postures and Policies to Operational Effects and Costs Across Phases of Operations

In December 1996, Bob Roll, then the resource management program manager in Project Air Force, asked me to return to RAND to lead efforts to strengthen PAF's logistics research capabilities and have them recognized within the Air Force and broader DoD senior leadership. At this time, Lt Gen Jumper was commander of U.S. Air Forces Central Command (AFCENT) and was interested in substituting speed for presence on the Arabian Peninsula following years of deployments to reinforce no-fly zones over Iraq following Desert Storm. Lt Gen Jumper called for the development of an Air Expeditionary Force that could meet these needs, starting first with small force packages such as those needed to replace a carrier strike force and then later to project larger force sizes around the globe very quickly. Bob Roll and I, recognizing that PAF's logistics expertise needed bolstering, worked an arrangement with the Air Force Logistics Management Agency (AFLMA) located at Maxwell Air Force Base to partner on research projects addressing the costs and effectiveness of alternative combat support postures to support the Air and Space Expeditionary Force (AEF) concept. In this partnership, the AFLMA would provide people with current logistics expertise, and PAF would provide people with analytic expertise to support important PAF projects sponsored by the Air Force. Over the years, the AFLMA provided several logistics subject-matter experts, including CMSgt John Drew, who would join RAND following his retirement from the Air Force, and Captain

Cauley Von Hoffmann, who would later become a Brig Gen in the Air Force Reserve.

During this time, I collaborated with several RAND researchers on projects involving the AEF theme, including Amatzia Feinberg, Eric Peltz, Mahyar Amouzegar, Lionel Galway, Tim Ramey, Paul Killingsworth, Amanda Geller, Hy Shulman, Jim Masters, Kristin Lynch, John Drew, Ron McGarvey, and others (see Amouzegar, Galway, and Geller, 2002; Amouzegar, Tripp, et al., 2004; Amouzegar, Tripp, and Galway, 2004; Feinberg et al., 2001; Galway, Tripp, Drew, et al., 1999; Galway, Tripp, Ramey, et al., 2000; Killingsworth et al., 2000; Leftwich et al., 2002; Lynch, Drew, Tripp, and Roll, 2005; Peltz et al., 2000; Tripp, Galway, Killingsworth, et al., 1999; Tripp, Galway, Ramey, Amouzegar, et al., 2000; and Tripp, Lynch, Drew, and Chan, 2004). The AEF projects extended over several years, and many of these assessed logistics posture options that could be used to rapidly project power around the world in small and large force packages. The work stressed the importance of establishing CIRFs so that heavy unit maintenance activities could be done at centralized sites and not at the place of employment to reduce materiel and people necessary to deploy and employ the force and, therefore, more rapidly project power. The work also showed the costs and effectiveness of alternative war reserve materiel (WRM) storage postures and how those postures could dramatically impact deployment and employment timelines for deploying forces. The work demonstrated the importance of assured transportation capabilities and LOG C2. Thus, the AEF research demonstrated the importance of creating responsive combat support postures, which included having a prepositioned logistics resources in various regions around the world to enable short deployment and employment timelines, as well as LOG C2 capabilities that could allocate scarce resources to units, which would enable achievement of most important operational effects.

In the Air Force, Major Cooper (to be Lt Gen Cooper), Colonel Gabreski (to be Lt Gen Gabreski), Grover Dunn, Brig Gen Mike Zettler (to be Lt Gen Zettler), Lt Gen John Jumper, and many other general officers on the Air Staff, major commands (MAJCOMs), Component Numbered Air Forces (C-NAFs), and component major commands

(C-MAJCOMs) were briefed on this work and supported the development of the concepts. When the air war over Serbia broke out, Colonel Gabreski, the USAFE Deputy Chief of Staff for Logistics, with the support of General Jumper, then the commander of USAFE, decided to test the CIRF concepts to support deployed units conducting the war effort (Peltz et al., 2000, and Feinberg et al., 2001). The CIRFs were located at Lakenheath Air Base and Spangdahlem Air Base and performed repair work on two types of engines, electronic systems and associated spare parts, and selected pods.

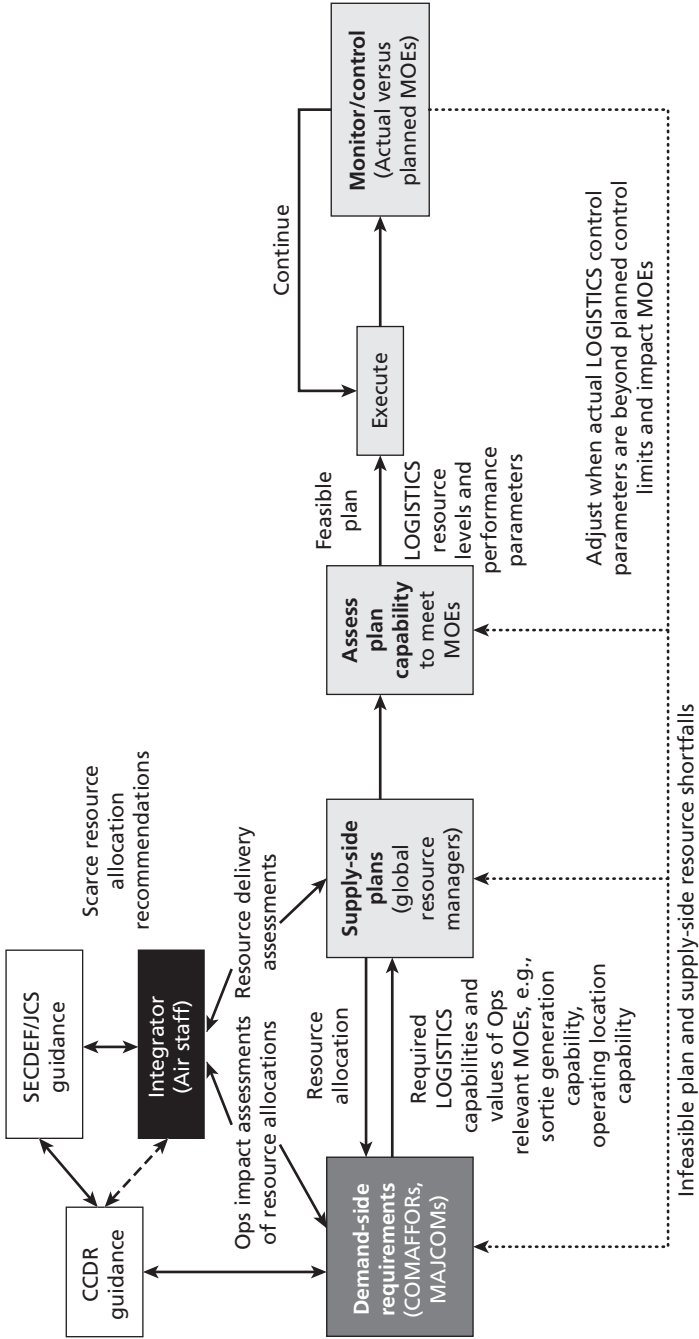
Within PAF, the AEF theme and the lessons learned from the air war over Serbia on implementing CIRFs and on LOG C2 shortfalls brought attention to the necessity of continuing work on enduring themes of relating logistics resource allocations and postures to operational effects and building and retaining research staff steeped in these research topics. Within the Air Force, attention on CIRFs and LOG C2 and the larger topic of how to improve logistics planning, execution, monitoring, and control across PPBES received attention from a new crop of logistics general officers, including Lt Generals Sullivan, Zettler, and Gabreski; Maj Gen McMahon; and many other senior logistics leaders. Grover Dunn, who had worked at AFLC with General Mullins and me, had reached Senior Executive Service (SES) status on the Air Staff charged with logistics innovation. Grover Dunn recognized the importance of LOG C2 and began to sponsor several LOG C2 projects that would extend over several years. I want to emphasize that, in addition to the senior logistics leaders mentioned above, many senior operations officers also paid attention to this research, including Generals Jumper, Chandler, North, Carlisle, and Breedlove; Lt Gen Elder; and many others. I believe one of the keys to getting our work implemented is to show senior operators how our work impacts operational effectiveness. Without senior operator support, our work is likely not to be implemented. Therefore, building relationships with senior operators is a fundamental part of conducting successful logistics research.

Around 1999, Bob Roll began taking a special interest in LOG C2 and encouraged me to examine the strategies-to-task (STT) work that Ochmanek and Kent had developed (see Schrader et al., 1996), as

well as the work that he and Leslie Lewis had done for United States Forces, Korea (USFK), in which they applied a resource-constrained SST framework to the Korean problem set. This framework gave me additional insights into how logisticians could improve communications with senior operations leaders. This work helped our logistics researchers at RAND refine an approach to demonstrate how better logistics planning, execution, monitoring, and control processes could improve the operational contingency planning processes by considering the operational impacts of scarce resource allocations and improving the dialog on how logistics options impact operational objectives. This work can also be viewed as the application of non-market economics to the allocation of scarce resources in military contingency planning efforts. In this work, Bob and I introduced the notion of the *demanders* of resources, the *suppliers* of resources, and a *neutral integrator* who would make resource allocation decisions as to which set of demanders would get scarce resources and which would not.

The left side of Figure 9.1 shows how the demanders (dark gray box), suppliers of logistics resources (light gray boxes), and neutral integrator (black box) concepts were integrated within the planning, execution, monitoring, and control concepts developed in the PACAF CSCMS project in the early 1980s. The introduction of the demander, supplier, and neutral integrator concepts also provided an analytic framework for assigning organizational authorities and responsibilities for performing some of the functions outlined in emerging and nascent LOG C2 concepts. As shown on the left side of Figure 9.1, demanders of resources, such as wartime commanders of Air Force Forces (COMAFFORs), would state requirements for logistics capabilities, while suppliers of logistics capabilities would determine when those capabilities could be supplied. The supply-side organizations, including Air Force Materiel Command, Air Combat Command, and others, would provide assessments of when and whether the supply-side organizations could meet demand-side needs, and if the requirements could not be met, they would alert the demanders of resources of their inability to meet capability demands. The demanders could then determine whether there were alternative means of achieving the desired operational effects and, if possible, would then provide revised

Figure 9.1
Supply-Side, Demand-Side, and Neutral Integrator Roles in Enhanced LOGISTICS Closed-Loop Planning, Execution, Monitoring, and Control System Processes



NOTE: CCDR = combatant commander. MOEs = measures of effectiveness.

estimates of logistics capabilities associated with the new plan to the supply side; this process would repeat until a logistically supportable plan was developed. The assessments conducted by the supply side need to be specified in terms of how resource allocations and logistics process performance would be expected to impact operationally relevant metrics, as discussed earlier. If the demander could not achieve desired effects given available resources, the neutral integrator would determine whether to reallocate existing resources to satisfy the demands and from whom to take resources. In concept, Figure 9.1 shows a version of the Pyles and Tripp contingency planning and operational tracking subsystems integrated into the demand, supply, and neutral integrator analysis framework.

Figure 9.1 identifies two such operationally relevant metrics: sortie generation capability and the number of operating locations that can be opened. These assessments need to be provided to the neutral integrator, shown here as Headquarters Air Force, who would advise the Secretary of Defense (SECDEF), to provide guidance to the supply side on which demanders should receive priority for scarce resources. The supply side would then balance resources across all types to ensure that, when a limit is reached in one resource, all others are balanced to not oversupply demands with some resources when combat capability has been limited by others.

Also, in 1999, Jim Leftwich joined me at RAND and led research that outlined how improving logistics planning, monitoring, execution, and control processes could enable the AEF concept. Leftwich's research team took the demand, supply, and neutral integrator concept, including the refined version of the Pyles and Tripp supply-side planning, execution, monitoring, and control process framework and showed how these processes could enable AEF concepts across the readiness/deliberate planning, crisis action planning, deployment, employment, and sustainment phases of operations. This work focused on how enhanced supply-side planning, execution, monitoring, and control processes could be integrated within collaborative and integrated operational and logistics planning processes. It stressed how proactive logistics planning that was integrated into the operational planning

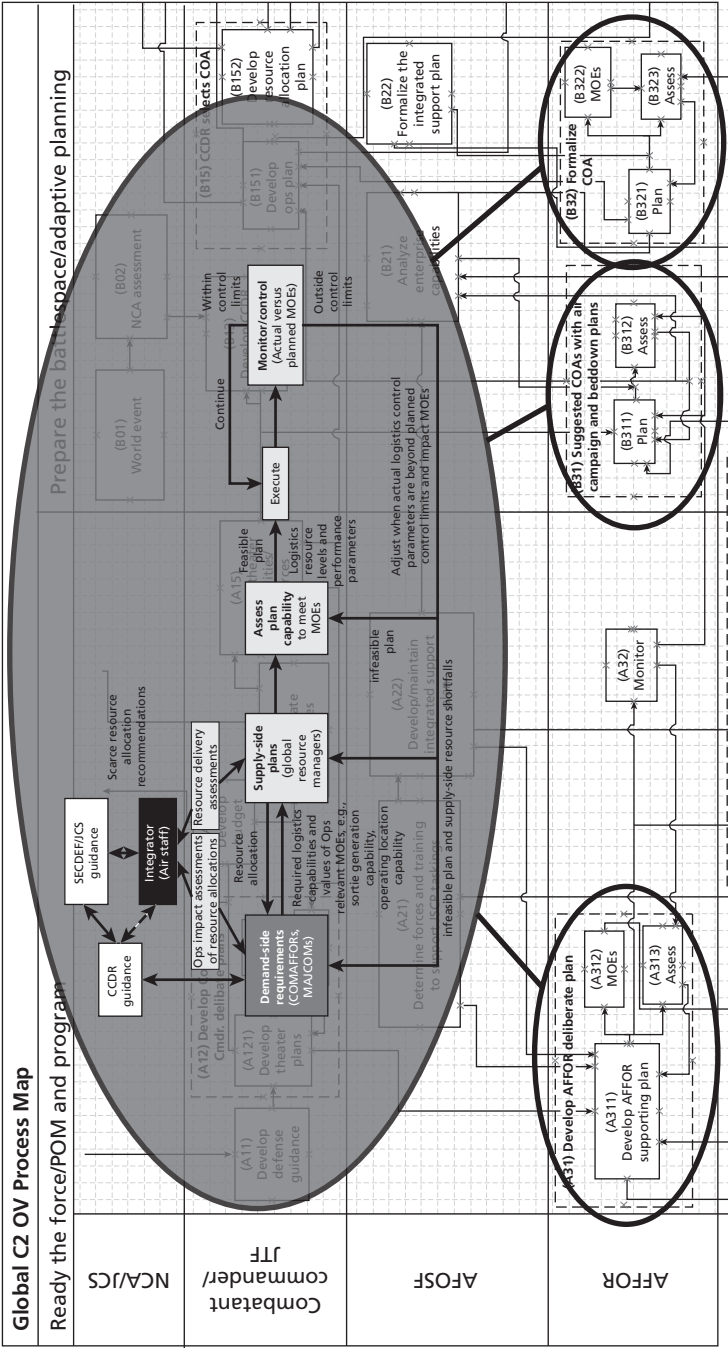
cycle could reduce the risk of executing operational plans that would not be logistically supportable.

Figure 9.2 illustrates how the operational architecture conceptually inserted these enhanced collaborative interactive operations and logistics assessments across the phases of operations. The top of the figure shows the operational phase of concern from steady state and readiness preparation to employment/sustainment. The operational architecture identified how the framework would be applied across the echelons and who would be responsible for executing the enhanced processes. The architecture indicated that process changes needed to occur from the SECDEF down to the wing level and included descriptions of COMAFFOR and Air and Space Operations Center (AOC) processes.

The operational architecture indicated that the Air Force needed two standing organizations to work with operational planners to provide integrated logistics—and, more broadly, combat support—capability assessments to COMAFFORs and Joint Force Air Component Commanders (JFACCs) charged with planning and executing air campaigns for the combatant commanders. One of these organizations was a Global Integration Center. This center would provide integrated assessments of logistics capabilities and constraints associated with each operational plan from a worldwide perspective and alert planners of plans that were not supportable. This organization would then interact with theater operational planners until a feasible plan was developed given national logistics capabilities and constraints. Once a feasible plan was established, resources would be allocated to approved plans.

The operational architecture also indicated that additional organizations called operational support centers were needed to allocate scarce resources to combat organizations with the highest priorities within the air component of combatant commander organizations. These operational support centers would be assigned to COMAFFORs and would conduct analyses to inform allocation and reallocation of resources that were approved for use within the area of responsibility (AOR) to meet specific combatant commander objectives. A combatant commander may have several operational plans that may need to be executed, and the operational support center would help recommend

Figure 9.2
The LOG C2 Operational Architecture Shows How Enhanced Logistics Planning, Execution, Monitoring, and Control
Processes Impact Processes Across the Entire PPBES



NOTES: AFFOR = Air Force Forces, AFOSF = Air Force Operational Support Facility, JCS = Joint Chiefs of Staff, JTF = Joint Task Force, NCA = National Command Authority, POM = program objective memorandum.

resource allocations among the plans and within areas of responsibility in accordance with combatant commander priorities.

This operational architecture was widely briefed and accepted by the Command, Control, Intelligence, Surveillance, and Reconnaissance (C2ISR) Center and Air Staff leaders. Because the architecture dealt with improving multi-echelon LOGISTICS—or what the Air Force called agile combat support (ACS)—processes within the Air Force and Joint C2 enterprise, AFMC and Air Combat Command (ACC) were particularly engaged in understanding and implementing improvements to these processes.

From my view, many of these ideas were related to the focus areas that General Mullens brought to the attention of the Air Force community in the early 1980s. These ideas were refined by the CLOUT work of Cohen, Lippiatt, and Abell and expanded the work of Roll, Lewis, Pyles, Tripp, and many others at RAND during the previous 20 years.

2003 to 2011: Expanding Logistics Analyses to Focus on Enterprise-Wide Impacts

During this period, senior logistics and operations officers were keenly interested in PAF logistics research and sponsored a series of Logistics Enterprise Analyses (LEAs). These efforts included continued detailed analyses of CIRFs, with new analyses addressing the effectiveness and efficiencies of CONUS engine CIRFs (McGarvey, Masters, et al., 2008) and CIRFs dedicated to performing fighter phase inspections and strategic lift, tactical lift, and tanker isochronal inspections (McGarvey, Carillo, et al., 2009; Tripp, McGarvey, et al., 2010; and Van Roo et al., 2011). Separate LOG C2 analyses were launched to refine the concepts and support Air Force tests of the concepts. Work also continued on WRM posture analyses as part of the LEA theme to determine where WRM should be stored to support rapid global force projections to AORs of interest.

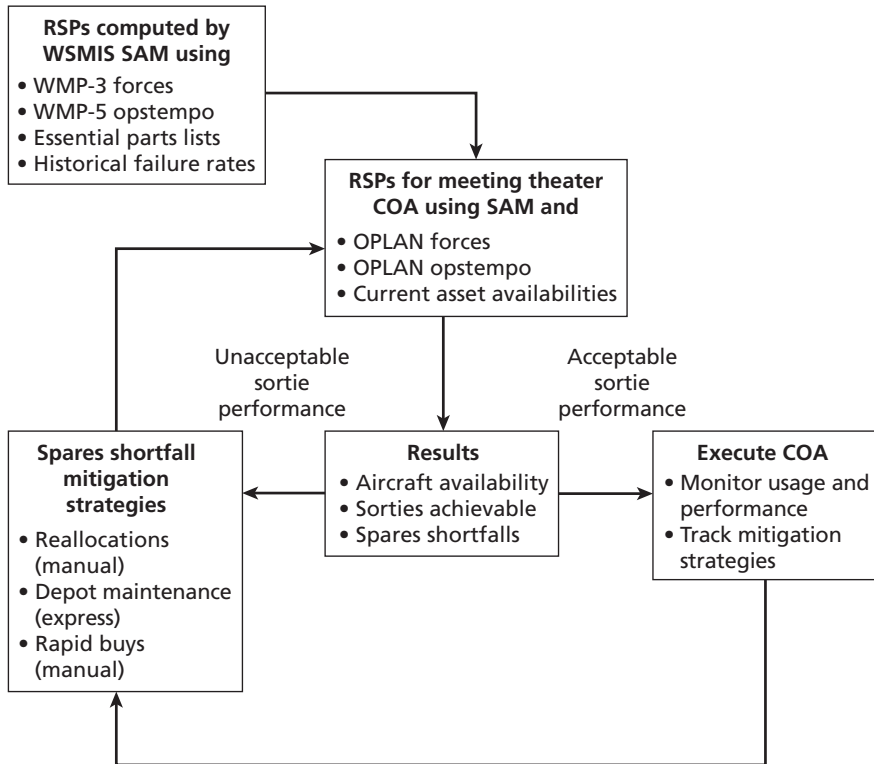
The LEA work stressed the importance of having responsive logistics processes to address uncertain events and reap manpower and other resource savings resulting from improved maintenance efficiency in CIRFs. These manpower savings could be applied to meet unfunded combat needs, for example, by providing resources to support smaller-than-squadron-size deployments (split operations). The PAF Logistics Enterprise Analysis work was supported by Generals Gabreski, McMahon, Zettler, Wolfenbarger, Sullivan, and others. During this period, I organized quarterly meetings to brief the most-senior logistics leaders in the Air Force on the latest research. When Lt Gen Gabreski was AFMC Vice Commander (AFMC/CV), she and the Air Staff

Deputy Chief of Staff for Logistics and Installations would chair these LEA update sessions, and logistics leaders from the major commands, AFMC, the Air Staff, and ALCs would attend the sessions. This work produced a vision for the logistics system of the future, which has been identified in several RAND publications. This LEA work and other projects informed the Air Force Repair Network Initiative directions and scope. This work also informed WRM posture thinking.

During one of the LEA sessions, I was briefing the contents of our LOG C2 work and indicated to Lt Gen Reno, AF/A4, and Lt Gen Gabreski, AFMC/CV (with retired Lt Gen Zettler present as an invited interested party) that the Air Force logistics community did not know whether it could support current contingency plans because they did not assess the readiness of the enterprise to meet demands as created by the operational planning community, as we had called for in our LOG C2 concepts. Lt Gen Gabreski took up the challenge and authorized AFMC staff to undertake the theater-wide assessment of 3rd and 13th Air Force contingency plans. The effort was called the AFMC Combat Support Planning and Execution System (C-SPEC) Experiment.

As shown in Figure 10.1, the WSMIS theater-wide assessment system that was put in place 25 years earlier was resurrected as the principal analysis tool to accomplish these C-SPEC assessments. Lt Gen Gabreski authorized the creation of a small capability assessment organization to accomplish these C-SPEC assessments. These assessments showed that sortie generation capability would be severely restricted because of spare parts shortages. The analysis further showed that sortie generation capability could be significantly enhanced by reallocating serviceable worldwide stocks to tasked units and tasking the depots to repair spares needed to support the wartime effort. I participated in the assessments, and our RAND LEA team provided support as necessary. The analyses also showed that sortie generation capabilities could be significantly enhanced by prioritizing AFMC Air Logistics Center (ALC) and contractor repair actions to raise the levels of serviceable spares. Notice that EXPRESS, which was based on the DRIVE algorithm described earlier, was used to push needed items into repair and to distribute the items to the units where the allocation of serviceable items would raise worldwide weapon systems availability

Figure 10.1
The AFMC Combat Support Planning and Execution System Used WSMIS
Capabilities Developed in 1985



NOTES: COA = course of action. OPLAN = operation plan. opstempo = operations tempo. SAM = sustainability assessment module. WMP-3 = *War and Mobilization Plan*, Volume 3. WMP-5 = *War and Mobilization Plan*, Volume 5.

the most. These were the specific benefits that our LOG C2 work and earlier CLOUT work indicated would result from implementing our LOG C2 concepts at the depot level and linking that C2 to theater LOG C2 actions.

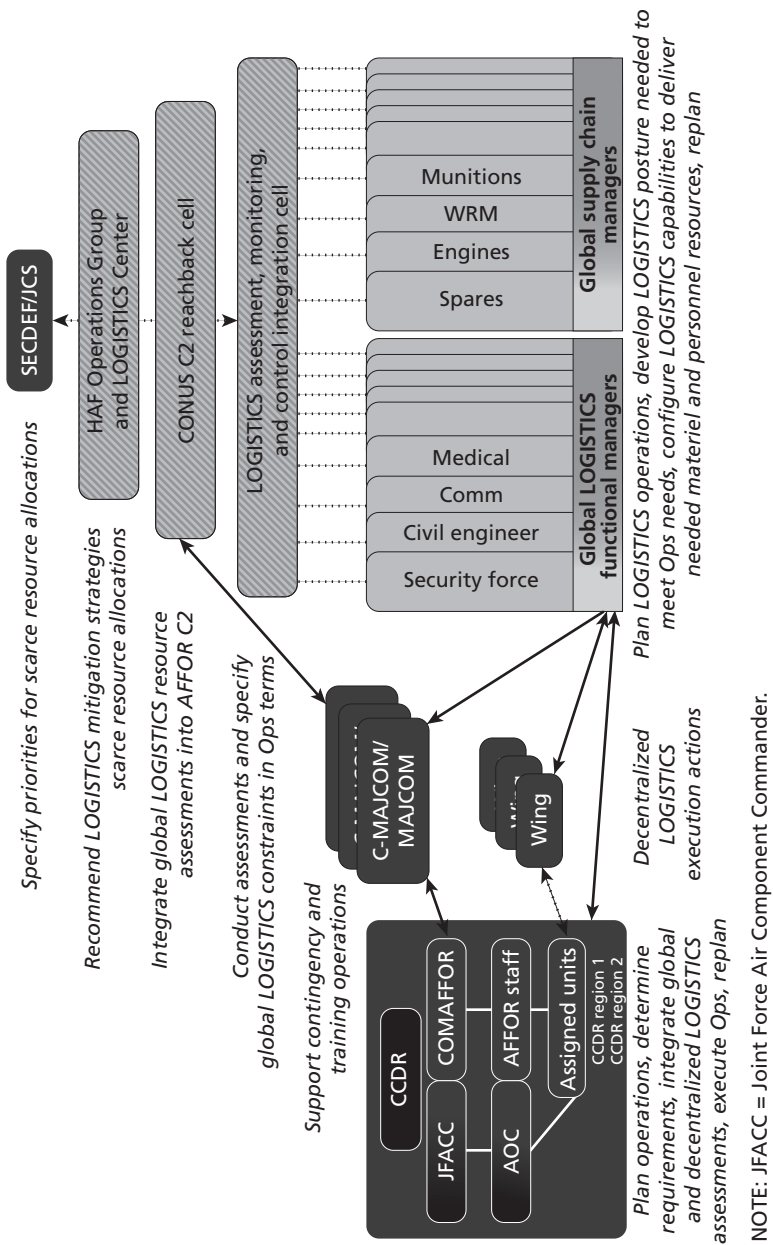
Lorna Estep, then the SES civilian assistant to the AFMC Deputy Chief of Staff for Logistics, and I briefed the results of the C-SPEC analyses to commanders of 3rd Air Force, 13th Air Force, and 7th

Air Force; the commander of AFMC; and several other senior leaders, including sessions at the C2 General Officer Steering Group (GOSG) conferences. These briefings always stressed the value of conducting theater-wide readiness assessments from the viewpoint of a global supplier of resources. Thus, in a small way, the C-SPEC activity brought attention back to the importance of having AFMC assess its readiness to support major contingency plans.

Also, during this period, the senior operations community was very interested in how improving logistics processes with the C2 enterprise would enhance operational planning. At one point, the LOG C2 work was one of the top five priorities of the C2 GOSG. Because of this senior officer interest in LOG C2, an Agile Logistics Experiment (ALEX) was sponsored by the Air Force Command and Control Center within ACC to show the relevancy of the LOG C2 improved processes and identify how the improved processes could interface with the Air Force C2 enterprise. As indicated earlier, the supply, demand, and neutral integrator framework provided PAF analysts with a framework that could be used to assign logistics planning, execution, monitoring, and control processes to various C2 nodes.

Figure 10.2 shows the C2 nodes that were engaged in ALEX. Figure 10.2 shows the demanders for Air Force resources on the left side of the chart, including COMAFFORs who work for combatant commanders and develop wartime logistics requirements and MAJCOMs who establish steady state and training logistics requirements. The supply-side organizations are shown on the right side of the chart and include global combat support functional managers, global resource managers, and global supply chain managers. The gray striped organizational boxes show the organizational voids where no organization existed with responsibilities to conduct assessments on the supply side. As shown in Figure 10.2, a reachback LOG C2 cell is needed, which would receive resource demands from theater COMAFFORs. This reachback cell could also house the analytic machinery and analytic staff to conduct integrated global assessments of each theater's ability to support operational plans across all resources needed to initiate and sustain combat operations, including those needed to support combat sorties and open and sustain operating locations. In the LOG C2 oper-

Figure 10.2
The LOG C2 Structure Tested in ALEX



ational architecture described above, this organization was called the LOG C2 global integration center. Figure 10.2 also indicates that the Air Force needs an organization at the Headquarters Air Force (HAF) level to recommend scarce resource allocations among the theaters. Except for the munitions area, in which resource shortages are recognized and mechanisms to deal with shortages have been developed, the other logistics areas do not have organizations and formal mechanisms to make scarce resource allocation decisions. In the munitions area, a Joint Munitions Allocation Board and a Joint Munitions Movements Board have been established in recognition that shortages in this commodity will occur. The PAF LOG C2 research argues that resource shortages will exist in other commodities, including spare parts, engines, and base expeditionary airfield resources, and that the operations support center and neutral integrator functions needed to reallocate scarce resources among theaters must be established before contingencies begin and must be ready to reallocate scarce resources from one theater to another when needed.

ALEX was designed in part to understand whether analytic tools existed to conduct the resource assessments and to determine how assessment information could assist in scarce resource allocation decisions. ALEX used the Ryan Center at ACC as the global integration center node, which would house the reachback cell and conduct the integrated assessments, as called for in the PAF LOG C2 operational architecture and other work described above. The Air Force C2 center developed the desired learning objectives, which were centered on the feasibility of conducting theater-wide readiness assessments to meet planned contingency requirements and to identify information products that would allow the neutral integrator to view assessments and make resource allocation decisions based on theater priorities and operational impacts across theaters. ALEX involved analysis of the unplanned operational impacts of a contingency being initiated in the USAFE AOR and showed the results of sourcing this contingency on 13th AF and 7th AF scenarios.

During this time, the most-senior operations leaders, including the commanders of 3rd Air Force, 13th Air Force, and 7th Air Force, as well as senior logistics leaders, including the AFMC/CV and the

Deputy Chief of Staff for Logistics at the Air Staff, were briefed and supportive of implementing the capabilities identified in the LOG C2 Operational Architecture. The results of ALEX were briefed to the AFMC Commander, the ACC Vice Commander, the C2 GOSG, and others. Lt Gen Wolfenbarger, who succeeded Lt Gen Gabreski as AFMC/ CV, supported the development of the capabilities identified by PAF and held quarterly meetings with the ACC Vice Commander and the C2 functional senior leaders to discuss LOG C2 implementation actions. I point out again that this analysis and other LOG C2 work had the support of the senior operator community.

In 2011, Lt Gen Wolfenbarger was reassigned to become the military assistant to the Under Secretary of the Air Force for Acquisition. At that time, I briefed the ACC Vice Commander on the enhanced LOG C2 requirements and how they needed to be integrated into the Air Force and Joint C2 enterprise. The ACC Vice Commander, Lt Gen Rew, indicated that he supported the requirements but that AFMC or the Air Staff would need to fund these capabilities and ensure that the C2 systems would interface with this set of capabilities. With the transfer of Lt Gen Wolfenbarger from AFMC and the lack of support from the Air Staff at the time, this iteration of the LOG C2 effort was curtailed for the time being. The need for these capabilities would be recognized and resurrected again when the need arose to support operations in contested environments, as discussed later in these reflections.

2011 to 2014: Reorganization of AFMC and LOG C2 Stagnation

During this period, AFMC reorganized and reduced the number of centers and commanders that reported directly to the AFMC commander from 12 centers to five. This was a period of internal focus for AFMC; efforts to relate command policies and process performance to wartime operational effectiveness ceased for the most part, and LOG C2 efforts stagnated.

One of the major outcomes of the AFMC reorganization was the assignment of what were once ALC System Sustainment Managers' responsibilities to the SPO System Support Managers. The justification for this reorganization was to streamline the organization while implementing DoDI 5000 series in a fashion more consistent with the guidance and with other service organizations and at the same time reduce some manpower spaces through the consolidation of Headquarters functions. John Ausink and I led the congressionally mandated review of the AFMC reorganization, which had been raised primarily by the depot caucus in Congress and was supported by representatives of other regions in which AFMC had large organizations. Our RAND review team consisted of Ray Conley, Kristin Lynch, Dan Romano, and others. The team found that the reorganization had strengths and weaknesses and that one weakness of the new organization was the very weak linkages of the SPO System Support Managers in the AFMC Life Cycle Management Center with warfighters, including C-NAFs and C-MAJCOMs, and with the Air Force Sustainment Center (AFSC) item management, maintenance, and process engineering communi-

ties. The PAF report indicated that AFMC should develop LOG C2 capabilities that could address some of these linkage problems and help in assessing the readiness of weapon systems to meet their wartime taskings.

During the first few years after implementing the new organization, AFMC focused largely on improving internal processes, and establishing LOG C2 systems and assessment tools would wait until more attention was given to potential conflicts that might evolve with near-peer adversaries.

2012 to the Present: Examining Logistics Under Attack

In the summer and fall of 2011, General Breedlove, then Air Force Vice Chief of Staff, and Lt Gen Carlisle, Air Staff Deputy Chief of Staff for Plans and Operations, became increasingly concerned that near-peer potential adversaries, and especially China, posed serious challenges to U.S. Joint land-based air power projection and freedom of movement within the Pacific. They sponsored a PAF project entitled “Logistics Under Attack,” in partnership with Lt Gen Fedder, Air Staff Deputy Chief of Staff for Logistics and Installations, to examine vulnerabilities of land-based air forces to potential attacks from potential near-peer adversaries, beginning with China. This project would be extended over the next eight years and sponsored by several PACAF Commanders, including General Carlisle, General Robinson, General O’Shaughnessy, and General Brown. This set of projects examined expected vulnerabilities associated with potential Chinese kinetic attacks and evaluated the costs, effectiveness, and risks associated with assorted options designed to mitigate vulnerabilities. The Air Force refers to this set of projects as PAF’s Combat Operations in Denied Environments (CODE) body of work. The project has been expanded, and several additional analyses have been sponsored by OSD, the Joint Staff, the U.S. Transportation Command, the U.S. European Command, the Air Force Civil Engineering Center, and USAFE. Please note that these logistics-oriented analyses had the support of the most-senior operations leaders because they deal with how logistics impacts operational effectiveness—a key theme of some of our most successful

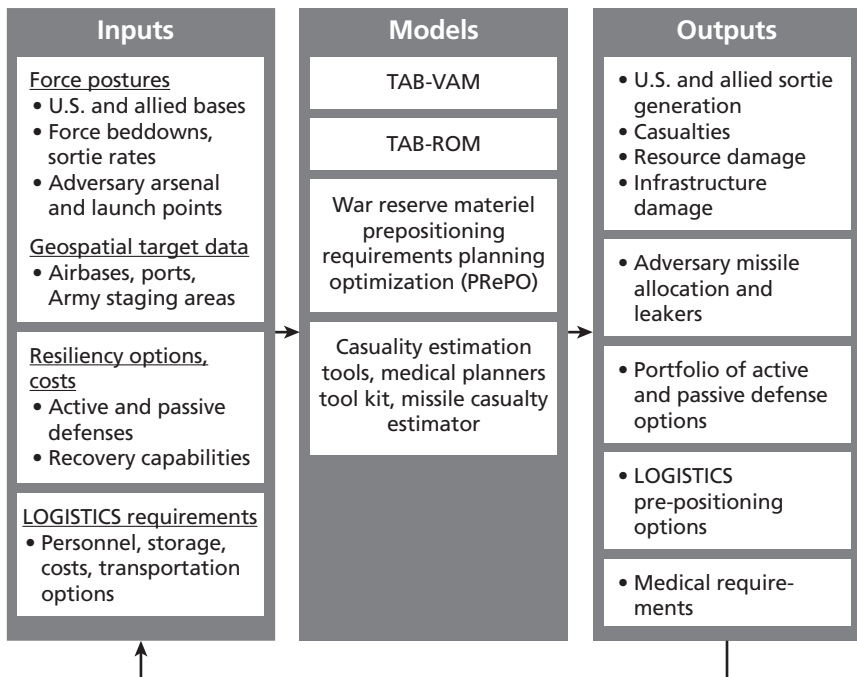
logistics work. We must always show the relevance of logistics analysis to the operational community and show how logistics options impact operationally relevant metrics—a key part of General Mullins’s vision for logistics analyses many decades earlier.

When Lt Gen Cooper succeeded Lt Gen Fedder as the Air Staff Deputy Chief of Staff for Logistics and Installations, he continued to work with the RAND CODE team and the Air Force logistics community to reestablish LOG C2 as an important part of the Logistics Flight Plan, which implements the Air Force Strategic Master Plan. In addition, a LOG C2 CONOPs has been written with leadership from both the Air Staff Deputy Chief of Staff for Logistics and Installations and the AFMC Air Force Sustainment Center Commander, as informed by PAF LOG C2 work over the years. Thus, the PAF LOG C2 concepts are currently included as requirements and recognized as being critical in supporting Air Force contingency planning and execution functions. The Flight Plan also indicates the importance of setting the theater and creating WRM postures that can enable operations in each AOR.

During this period, I led or co-led most of the CODE projects within PAF, working with Brent Thomas, Drew Karode, Rachel Costello, Chris Lynch, Dan Romano, Jacob Heim, Kate Pfrommer, Jordan Willcox, and many others to develop the CODE analytic framework to assess potential damages that might be incurred during kinetic attacks, translate these damages into operationally relevant metrics (e.g., sortie generation capability), examine the costs and effectiveness of a range of mitigation options, and select the portfolio of options that provides the greatest improvement to sortie generation capability across a set of attack vectors for given amount of investment. This team has developed the assessment model, the Theater Air Base Vulnerability Assessment Model (TAB-VAM), and an optimization model, the Theater Air Base Resiliency Optimization Model (TAB-ROM), which searches for the best “get-well plan” for a given amount of funding to mitigate projected damages resulting from attacks. Brent Thomas and Drew Karode deserve special recognition for developing the detailed analytic approach that is used in all CODE projects.

As shown in Figure 12.1, the CODE analytic framework has similarities with the planning subsystem associated with the Pyles and Tripp Note shown in Figure 4.1 and with the right side of the LOG C2 processes illustrated in Figure 9.1. In fact, the CODE analytic framework extends and enhances the Pyles and Tripp closed-loop C2 planning subsystem framework and the assessment portions of the logistics planning, execution monitoring, and control processes outlined in the PAF LOG C2 operational architecture work. The CODE analytic framework also enhances air base attack approaches developed by Emmerson, Dreyer, and others. The framework explicitly deals with state-of-the-world uncertainty by indicating that no one knows which bases a potential adversary will attack and which targets on the air base will be attacked. The specific target sets are large—e.g., parked aircraft

Figure 12.1
The Combat Operations in Denied Environments Analytic Framework



in the open or in shelters, runways, fuel storage, munitions storage, personnel, and so forth.

The CODE analytic framework deals with state-of-the-world uncertainty in much the same way as the financial community does when it selects investment portfolios that are robust against potential stock market uncertainties. The CODE framework seeks a portfolio of mitigation options that would be robust against a variety of potential adversary attacks. TAB-VAM examines a large array of possible attack vectors and computes potential damage profiles resulting from each. TAB-ROM then examines how various combinations of vulnerability mitigation options would affect sortie generation capability across a wide range of possible attack vectors—e.g., the best adversary attack vector and a set of attack vectors near that vector that can create significant damage. TAB-ROM then selects the portfolio of mitigation options that provides the greatest improvement in effectiveness—i.e., sortie generation capability—for each increment of investment considered for the set of vectors that can cause the most-significant decreases in sortie production.

The CODE work has influenced out-of-cycle POM funding for resiliency resources in the Pacific and influenced the design of the WRM posture in the AOR. The analytic approach has been recognized as being innovative within RAND and within the DoD community, receiving recognition for its innovative analyses.

From my view, the CODE analytic framework is an extension of the WSMIS assessments conducted over 30 years ago as inspired by General Mullins. Likewise, resiliency optimization capabilities analysis are akin to the WSMIS get-well analyses that were pioneered long ago. These assessments need to be part of the development of contingency courses of action, as demonstrated in WSMIS and AFLC LOC assessments, to ensure that there are adequate logistics resources to initiate and sustain a campaign. This is the function of the planning subsystem as developed in the Pyles and Tripp LOG C2 concept and envisioned by General Mullins.

To facilitate implementation of the concepts within the Air Force and DoD more generally, from my view, RAND should provide TAB-VAM and TAB-ROM to DoD organizations, including PACAF/Stud-

ies, Analysis and Assessments (A9), AF/A9, USAFE/A9, and OSD CAPE, among others—just as RAND released Dyna-METRIC and DRIVE to the Air Force when I was at AFLC. Consistent with this thinking, some years ago, PAF approved the release of a draft copy of TAB-VAM to AF/A9 per their request to use the draft copy of the model to support an OSD-mandated tanker vulnerability assessment. At the time, AF/A9 did not have modeling capabilities similar to TAB-VAM and still does not to this day. AF/A9 currently uses TAB-VAM in several applications, and RAND has provided them with enhancements to the model over time in a similar way that RAND updated Dyna-METRIC for AFLC when WSMIS was being developed. At the time of this writing, USAFE/A9 has requested a copy of TAB-VAM and TAB-ROM.

From my perspective, we should release our models to the Air Force and others in DoD who have worked closely with us and who recognize that we have truly unique analytical tool sets that can meet larger DoD analytic needs. This goes back to the discussions that I had with General Mullins in which he indicated that if we wanted to have ideas live over time that we would need to ensure that Air Force organizations and their supporting contractors would take possession of the ideas and associated tool sets and thus use their interests and incentives to expand the ideas and improve the tool sets over time. RAND is a relatively small organization, and our unique approaches need to be adopted and sustained by the Air Force. We cannot sustain the continuous support of models and databases that we develop to solve unique problems, so we need to pass them on to the Air Force for implementation actions, which can take many years.

Also, during this period, Brent Thomas and I led two projects for U.S. European Command to expand and enhance the CODE analytic framework to examine potential vulnerabilities of U.S. land-based air forces to potential attacks from Russia. Through this project, we have informed USAFE operational and logistics planners of the vulnerabilities of current operational force beddown and associated WRM locations associated with current contingency planning efforts and recommended reevaluation of their beddown plans.

Our CODE team has also initiated work with the Joint Staff, Force Structure, Resources, and Assessment Directorate (JS-J8) to conduct assessments across all AORs as part of their Joint Regional IAMD Capability Mix Analyses. These efforts have led to Joint Staff, Logistics Directorate (JS-J4)—supported and U.S. Transportation Command—supported analyses, all of which have extended and enhanced the CODE analytic framework. At the time of this writing, we have completed seven years of work on CODE projects and have had on the order of 27 projects sponsored by OSD, the Joint Staff, the Air Staff, PACAF, U.S. Transportation Command, U.S. European Command, USAFE—Air Forces Africa, and others.

The CODE analytic approach has continuously been enhanced to add target sets and mitigation options to the algorithms to the point where it now has been used to assess vulnerabilities and develop mitigation options across all AORs. From my view, the CODE analytic framework can be at the core of an Air Force and DoD readiness assessment system that incorporates uncertainty, including potential adversary actions, into assessments that can be used to report potential impacts of adversary attacks combat effectiveness—as Dyna-METRIC was used in the development of WSMIS, going back to the initiatives supported by General Mullins during the 1980s.

The RAND management team has recognized the importance of the CODE work and has encouraged expansion of the CODE analytic framework. The management team has also nominated briefings from the CODE team to be presented to the PAF steering group and RAND board of trustees. In addition, several RAND CODE team members have won RAND medal awards acknowledging the impact of their contributions.

At this point, individual researchers and program managers within RAND will need to carry this readiness assessment theme forward, including enhancements of assessment models like TAB-VAM and optimization models like TAB-ROM, and move these capabilities from our internal use into the DoD community for use in formal assessment systems. This will be an area in which our research team and others at RAND will need to ensure that the models have received sufficient quality assurance to allow them to be handed over to our

sponsors and embedded in Air Force and DoD capability assessment systems.

There remains much to do within the Air Force and larger DoD community to implement and institutionalize our readiness assessment and LOG C2 concepts. Although the Air Force has developed a LOG C2 CONOPs, no office has been assigned the responsibility for developing the capabilities outlined in the CONOPs, and no POM initiative has been developed to fund the continued development on the embryonic capabilities that have been provided to AF/A9. The Air Force will always have tough resource allocation decisions to make, and RAND researchers will need to work with key Air Force champions to move these ideas from concept to implementation. This will take time, and, if the ideas are to be institutionalized, it will take work to keep the importance of these ideas in front of the Air Force leadership until they are implemented.

Within OSD, the new National Defense Strategy gives attention to ensuring that the Joint U.S. forces can deploy rapidly with sufficient logistical resources to meet the challenges in two prioritized AORs where the United States may engage in potential conflict with near-peer adversaries. With this top-down push on effectiveness of the force in contested environments, the timing is right to continue this theme of research for a considerable period. It will take time to implement the concepts we have developed, and RAND researchers and management teams will need to keep these ideas alive, as we have in the past, while steps are taken to implement portions of the concepts that we have developed. It will take years, if not decades, to implement the full range of concepts that we have developed.

Moving Forward: Designing Logistics Systems to Be Responsive to Unanticipated Events

Within the Air Force, there is growing recognition of the need to develop LOG C2 concepts and systems and other adaptive mechanisms in the design of logistics postures that can deal with the uncertainties associated with conducting combat operations in contested and degraded environments. As mentioned earlier, the Air Staff Deputy Chief of Staff for Logistics and Installations and the Commander of AFMC's Air Force Sustainment Center have developed a LOG C2 CONOPs that includes many of the LOG C2 concepts developed by PAF over the last 40 years. Brig Gen Hill and Brig Gen King, the latest PACAF/A4s, have asked for support to develop a combat support posture that can deal with uncertainties associated with potential contingencies that might eventuate in that AOR.

Also, as mentioned above, the SECDEF has come out with a new National Defense Strategy that can be used to guide operational planning and resource allocation decisions. In addition, the SECDEF has recognized the Chairman of the Joints Chiefs of Staff as the global integrator of the Joint Logistics Enterprise, and RAND has been awarded a relatively large project that asks for assessments of the effectiveness of current processes that shape the development of the Joint deployment and sustainment enterprise posture that is used to execute joint deployment and sustainment actions in contingency operations. In addition, further PACAF CODE, Joint Staff CODE, and U.S. European Command CODE projects are all being supported by senior leaders throughout the DoD community. These projects will once again

provide opportunities for the RAND research community to advance the closed-loop planning process articulated long ago in our LOG C2 work.

Within PAF, there is recognition that TAB-VAM and TAB-ROM can deal explicitly with some state-of-the-world uncertainties associated with potential adversary targeting strategies, but there are other uncertainties that need to be addressed as well. Some of these include the timing of when an adversary may commit to combat operations and when an adversary will cease combat operations, the willingness of potential allies to support U.S. combat operations, and how special operations and nonkinetic attacks might impact land-based air forces' vulnerabilities and combat effectiveness.

As pointed out in the arguments that Cohen, Rich, and others have made, prediction is necessary, especially in the programming venue, to obtain reasonable sets of single-purpose resources. At the same time, there needs to be much more attention given to building adaptive mechanisms and systems that can respond quickly to unanticipated events. The CLOUT work of the 1990s pointed to the need to develop real-time information on asset locations, process performances, demands, and weapon system priorities by operating locations. In the Pyles and Tripp LOG C2 framework, this is the purview of the operational tracking and control subsystem. Armed with this information, a LOG C2 system could then allocate scarce resources to where they are most needed, given assured distribution and transportation capabilities. Logistics system designs could then be developed to provide robust repair capabilities through mutual support of operating locations sharing the same aircraft mission design series or by using CIRFs that have built-in slack capacity to deal with unanticipated demands.

Members of the PAF and larger RAND research and management teams understand the need to address logistics systems designs that can operate in the world where near-peer adversaries can contest operations, damage operating locations and resources at those locations, disrupt and damage resupply networks, and interrupt or delay communications systems. Work is needed on how to ensure logistics communications about asset status, given the potential for disruption of communications. Work is needed to understand how to pro-

vide assured transportation to meet logistics needs in very dangerous environments. Research is also needed to determine how much “safety stock” should be purchased to deal with loss of resources and where this safety stock should be located. This theme will be important for decades to come.

Were Irv Cohen alive today, he would be pleased to know that PAF understands the limitations of “predicting” future results, as outlined in the CLOUT work. He would also likely be pleased that Air Force leaders and PAF researchers are focusing attention on how to combat state-of-the-world uncertainty. He would agree that much more attention is required to design adaptive mechanisms such as LOG C2, responsive maintenance, and responsive distribution capabilities into logistics system designs. RAND researchers can and should play a key role in working with the Air Force and larger DoD community to ensure that these capabilities are embedded within the Air Force and DoD logistics system designs as the threats and external environment change over time.

RAND will need to attract and retain researchers who are willing to work in the logistics field of research over long time horizons. It takes time to learn the breadth, depth, and complexity of how military logistics functions and, more important, logistics policy, processes, technologies, training, postures, and design options impact combat effectiveness. From my view, RAND researchers working in logistics will need to be able to articulate how logistics policy and system design efforts relate to combat effectiveness. They can benefit by attending a weapons employment course, as I did 40 years ago. As General Mullins pointed out in his recent communications with Michael Rich, combat effectiveness is the ultimate aim of the military, and logisticians and logistics analysts always need to understand and communicate how logistics options impact combat effectiveness.

RAND logistics analysts will need to continue to take a systems approach to dealing with logistics problem formulations. This means that analysts working in this area require the necessary education on how systems problems can be decomposed into workable areas and require knowledge of how these subsystems interact to affect overall systems behavior. Knowledge of quantitative analysis techniques and a

good understanding of economics are important because most logistics analyses deal with the allocation of scarce resources among competing uses for those resources.

RAND logistics analysts will always work in a very complex environment. RAND researchers will need to understand what they know and what they do not know. Judgments on approaches to take, the level of abstraction to use, the adequacy of our analytic approaches, the quality of the data, and the assumptions that we use will always be subject to question. Researchers will need to be humble about how they conduct their analyses and know the limits of what they can offer to senior leaders facing very difficult decisions.

From my perspective, we need to always be mindful that we can make mistakes or might not have the entire picture of how our analyses can impact the problem space. We often work in problem spaces in which the “truth” can never be known and, if we are sincere and approach our communications internally and externally with the right attitude, our sponsors and colleagues will help us understand the bigger picture and work with us much as a stretched rubber band to snap us back to a place where the “stretch” will not break the band that ties the system together. I think these are some of the fundamental issues that Irv Cohen, Hy Shulman, Lt Col Chuck Doryland, and General Mullins, among others, have tried to teach me and that I have tried to pass along to RAND researchers that I work with on a routine basis. The problems that we face are difficult and complex, and creating a community of interest that works closely together year over year is the key to having our analyses make significant impacts.

Annotated Bibliography

John B. Abell, Louis W. Miller, Curtis E. Neumann, and Judith E. Payne, *DRIVE (Distribution and Repair in Variable Environments): Enhancing the Responsiveness of Depot Repair*, Santa Monica, Calif.: RAND Corporation, R-3888-AF, 1992. As of April 16, 2019: <https://www.rand.org/pubs/reports/R3888.html>

- This report describes the development and demonstration in prototype form of an improved approach to certain aspects of the management of component repair workload at Air Logistics Centers (ALCs). Specifically, current “snapshots” of the world-wide asset position, coupled with specified aircraft availability goals at bases and item characteristics drawn from standard Air Force Logistics Command (AFLC) data systems, are used by a computer-based algorithm called DRIVE (Distribution and Repair in Variable Environments) to prioritize component repairs and allocate the assets to locations worldwide in a way that approximately maximizes the probability of achieving the availability goals. The approach contrasts sharply with the current component repair system in which component repairs are a matter of negotiation at the ALC based on estimated repair requirements stated by the item manager and asset data that are six to nine months old at the time the repairs take place. The report also describes the policy and implementation issues that AFLC needs to resolve before fielding a production version of this improved approach.

John L. Adams, John B. Abell, and Karen E. Isaacson, *Modeling and Forecasting the Demand for Aircraft Recoverable Spare Parts*, Santa Monica, Calif.: RAND Corporation, R4211-AF/OSD, 1993. As of April 16, 2019:

<https://www.rand.org/pubs/reports/R4211.html>

- This report explores issues in forecasting and modeling the demand for aircraft recoverable spare parts to improve the Air Force's estimation of spares and repair requirements over quarterly, annual, and longer planning horizons. Specifically, it demonstrates the utility of approaches that account explicitly for nonstationarity and their superiority over current methods used by the Air Force Materiel Command for these purposes. The authors recommend using a weighted regression, a special case of the Kalman filter, for forecasting demand for high-demand items. This approach is a logical extension of Bayesian statistics, which explicitly accounts for nonstationarity in stochastic processes, assigning greater weight to more recent than to less recent demands. Coupled with an improved approach to variance estimation that assigns greater uncertainty to longer planning horizons than to shorter ones, this holds the promise of reducing the cost of spares investments while achieving adequate levels of system performance.

Mahyar Amouzegar, John Drew, and Robert S. Tripp, "A Simulation Model for the Analysis of End-to-End Support of Unmanned Aerial Vehicles," *International Journal of Applied Decision Sciences*, Vol. 3, No. 3, 2010. As of April 16, 2019:

<https://www.inderscience.com/offer.php?id=36101>

- The role of unmanned aerial vehicles (UAVs) in intelligence, surveillance, reconnaissance, and time-critical targeting in operations Enduring Freedom and Iraqi Freedom confirmed their utility in U.S. combat operations. However, because of an acquisition strategy intended to field UAVs as quickly as possible, the Air Force did not go through the usual processes of determining system requirements before design and production. These processes typically reveal important information about how to support aircraft systems. Without this information, the requirements for long-

term, end-to-end support of UAVs are unclear. In this paper, we present an analysis of support options for current U.S. Air Force UAV systems, including the Global Hawk, Predator, Pointer, Raven, Force Protection Airfield Surveillance System (FPASS), and Battlefield Air Targeting Camera Autonomous Micro-Air Vehicle (BATCAM), as well as, the Unmanned Combat Aerial Vehicle (UCAV). There is a trade-off between the need to field aircraft quickly and the need to determine logistics requirements. We have developed a new analytical tool, logistics implications capabilities assessment model (LICAM), that could help logisticians examine such trade-offs. LICAM simulates changes in fielding, operations, and support and evaluates how they affect a key operational metric, the ability of the UAVs to cover the target area.

Mahyar A. Amouzegar, Lionel A. Galway, and Amanda B. Geller, *Supporting Expeditionary Aerospace Forces: Alternatives for Jet Engine Intermediate Maintenance*, Santa Monica, Calif.: RAND Corporation, MR-1431-AF, 2002. As of April 16, 2019:

https://www.rand.org/pubs/monograph_reports/MR1431.html

- This report evaluates the manner in which Jet Engine Intermediate Maintenance (JEIM) shops can best be configured to facilitate Expeditionary Aerospace Force (EAF) deployments. It examines a number of JEIM support options, which are primarily distinguished by the degree to which JEIM support is centralized or decentralized and assesses the performance of each option for three jet engines: the F-100-220, the F100-229, and the TF-34. The report makes recommendations to facilitate agile combat support (ACS) for these engines.

Mahyar A. Amouzegar, Ronald G. McGarvey, and Robert S. Tripp, "A Decision Support Model for Global Basing Architecture," *Decision Line*, Vol. 44, No 1, January 2013. As of April 16, 2019:

<https://decisionsciences.org/wp-content/uploads/2017/07/Jan.2013DL.pdf>

- This article focuses on an analytic framework for evaluating options for overseas distribution and service hubs. The presen-

tation of this framework is important because it addresses how to assess these options in terms of the relevant programming costs, while considering a novel approach to scenario planning. This formulation evaluates the effective cost of the overall supply chain associated with meeting the training and deterrent exercises needed to demonstrate U.S. global power projection capability, and thereby deter aggression, while maintaining the necessary system capability to engage in major combat or humanitarian operations, as needed.

Mahyar A. Amouzegar, Ronald G. McGarvey, Robert S. Tripp, Louis Luangkesorn, Thomas Lang, and Charles Robert Roll, Jr., *Evaluation of Options for Overseas Combat Support Basing*, Santa Monica, Calif.: RAND Corporation, MG-421-AF, 2006. As of April 16, 2019: <https://www.rand.org/pubs/monographs/MG421.html>

- This report presents an analytic framework and model for evaluating options for overseas combat support (CS) basing. The authors develop several sets of deployment scenarios to measure the effect of timing, locations, and intensity of operational requirements on CS and to account for the inherent uncertainties in future planning.

Mahyar Amouzegar, Robert S. Tripp, and Lionel A. Galway, "Integrated Logistics Planning for the Air and Space Expeditionary Force," *Journal of the Operational Research Society*, Volume 55, 2004. As of April 16, 2019:

<https://www.tandfonline.com/doi/full/10.1057/palgrave.jors.2601704>

- The shift to a U.S. Air Force structured for expeditionary operations has presented the Air Force with a number of challenges in planning, executing, and support operations involving resources such as munitions, fuel, engines, avionics, and war reserve materiel. In an expeditionary world, the logistics support processes must be capable of responding to rapidly deployed forces, either by deploying along with the fighting units or by connecting support processes in permanent locations to the remote forces. In this paper, we present a general approach for reshaping logistics processes to meet Air Force expeditionary operational goals. We

develop capability-based logistics models consisting of rules and algorithms that compute process timelines and requirements for materiel, equipment, and personnel. We use both optimization and heuristic techniques to formulate a location–allocation solution that can further refine the process.

Mahyar A. Amouzegar, Robert S. Tripp, Ronald G. McGarvey, Edward W. Chan, and Charles Robert Roll, Jr., *Supporting Air and Space Expeditionary Forces: Analysis of Combat Support Basing Options*, Santa Monica, Calif.: RAND Corporation, MG-261-AF, 2004. As of April 16, 2019:

<https://www.rand.org/pubs/monographs/MG261.html>

- This report evaluates a set of global forward support location (FSL) basing and transportation options for storing war reserve materiel (WRM), which includes such CS resources as base operating support equipment, vehicles, and munitions. The authors present an analytical framework that can be used to evaluate alternative FSL options. A central component of the authors' framework is an optimization model that allows a user to select the best mix of land-based and sea-based FSLs for a given set of operational scenarios, thereby reducing costs while supporting a range of contingency operations.

Michael Boito, Cynthia R. Cook, and John C. Graser, *Contractor Logistics Support in the U.S. Air Force*, Santa Monica, Calif.: RAND Corporation, MG-779-AF, 2009. As of April 16, 2019:

<https://www.rand.org/pubs/monographs/MG779.html>

- This report addresses the Air Force option of choosing contractor logistics support (CLS) over organic support and questions that remain about its cost and efficiency, even about whether CLS is the best option. The report concludes that centralizing and standardizing data would help make them available across the Air Force. More important, to retain all its choices for logistics services throughout a system's life cycle, the Air Force should acquire the technical data rights near the start of the acquisition process.

Patricia M. Boren, Karen E. Isaacson, Judith E. Payne, Marc L. Robbins, and Robert S. Tripp, *An Evaluation of The VISION Execution System Demonstration Prototypes*, Santa Monica, Calif.: RAND Corporation, R-3967-A, 1991. As of April 16, 2019:

<https://www.rand.org/pubs/reports/R3967.html>

- This report describes the prototype development for a U.S. Army combat-oriented logistics execution system with VISION (Visibility of Support Options). The Army calls this system the Readiness-Based Maintenance System (RBMS). RBMS prioritizes repair and distribution of spare parts by maximizing the probability of meeting unit-level weapon system availability goals. The report discusses the feasibility, effectiveness, and usability of RBMS through the use of analytic demonstration prototypes. It outlines the methodology behind RBMS and describes the outputs it produces. It then presents findings on RBMS's potential value for the Army, describes the input data requirements and the availability of usable data in present Army data systems, and discusses evaluation results of the demonstration prototypes. Finally, the report presents prospective users' evaluations of the perceived usefulness of the system and suggestions for its improvement.

Bernice B. Brown, *Characteristics of Demand for Aircraft Spare Parts*, Santa Monica, Calif.: RAND Corporation, R-292, 1956. As of April 16, 2019:

<https://www.rand.org/pubs/reports/R292.html>

- This report presents the results of various RAND studies on the demand for aircraft spare parts. To reduce the occurrence of parts shortages to a reasonably low level, it is necessary to predict the probability that various demands will occur. However, demands cannot be predicted with confidence, so it is necessary to consider improvements in logistics operations to make it easier to live with demand uncertainty. Suggested improvements are shortened resupply time, procurement lead time, and repair cycle for spare parts.

Irv K. Cohen, John B. Abell, and Thomas F. Lippiatt, *Coupling Logistics to Operations to Meet Uncertainty and The Threat (CLOUT): An Overview*, Santa Monica, Calif.: RAND Corporation, R-3979-AF, 1991. As of April 16, 2019:

<https://www.rand.org/pubs/reports/R3979.html>

- Uncertainty is of essentially two kinds: statistical uncertainty (variability observed in repeatable phenomena), and state-of-the-world uncertainty (uncertainty about phenomena that are not repeatable, not observed or observable, or both). State-of-the-world uncertainty dominates the wartime scenario and affects peacetime planning as well. This report describes a set of initiatives called CLOUT (coupling logistics to operations to meet uncertainty and the threat) designed to cope with resource shortages caused by poor predictions of demand. The theater-level CLOUT initiatives include (1) lateral repair by bases that have repair capability to support bases that do not; (2) forward stockage for quick response to unsatisfied demands at bases; (3) responsive theater transportation to support lateral resupply, forward stockage, lateral and theater repair, retrograde, and distribution of assets coming into the theater; and (4) improved operating policies and decision rules in prioritizing repair assets and allocating them to bases. The “wholesale” or depot-level CLOUT initiatives include the following: (1) responsive, assured inter-theater transportation; (2) enhanced flexibility, responsiveness, and relevance of the depot’s repair process; and (3) distribution of serviceable assets that explicitly accounts for mission urgency and the current asset position worldwide.

Cynthia R. Cook, John A. Ausink, and Charles Robert Roll, Jr., *Rethinking How the Air Force Views Sustainment Surge*, Santa Monica, Calif.: RAND Corporation, MG-372-AF, 2005. As of April 16, 2019: <https://www.rand.org/pubs/monographs/MG372.html>

- Sustainment surge describes the increase in weapon systems repair activity brought on by the operational demands of wartime or contingency operations. In light of changes in force posture constructs to respond to multiple but small contingencies, the report

looks at how the nature of surge has changed, how its management may be affected by legislation, and whether the effectiveness of surge planning can be improved.

Gordon Crawford, *Variability in the Demand for Aircraft Spare Parts: Its Magnitude and Implications*, Santa Monica, Calif.: RAND Corporation, R-3318-AF, 1988. As of April 16, 2019:

<https://www.rand.org/pubs/reports/R3318.html>

- Mathematical models of the logistics system are used to determine spares requirements, and they play an important role in evaluating logistics policies. The kernel of many, if not most, of these models is the modeling of the failure process and the resulting series of random demands on supply and maintenance. This report describes the assumptions of these models and quantifies ways in which the behavior of the data differs from the assumptions of the models. The differences are pervasive and important. In addition, an examination of the number of parts in the repair pipeline over time reveals even more variability than does the number of demands over time. These observations have two important consequences: (1) excessive demand variability substantially reduces the confidence we can put in our requirements and capability assessment models, and (2) highly variable repair pipelines with means larger than assumed by requirements models have a damaging effect on aircraft availability and wartime readiness. Depot policies, decisions, and goals should be aimed at reducing the number of parts in these pipelines and increasing aircraft availability and wartime readiness.

John G. Drew, Kristin F. Lynch, James M. Masters, Robert S. Tripp, and Charles Robert Roll, Jr., *Options for Meeting the Maintenance Demands of Active Associate Flying Units*, Santa Monica, Calif.: RAND Corporation, MG-611-AF, 2008. As of April 16, 2019:

<https://www.rand.org/pubs/monographs/MG611.html>

- The methodology developed in this research can be used to quantify and compare the key factors that allow the U.S. Air National Guard to generate peacetime training sorties with a fairly small

full-time workforce. The authors apply these insights to proposed Total Force Integration initiatives to evaluate maintenance options for supporting associate units, where the goal of the unit is to produce trained pilots in the most efficient manner possible. The methodology evaluates how various types of personnel can influence the size and productivity of a unit.

Amatzia Feinberg, Hyman L. Shulman, Louis W. Miller, and Robert S. Tripp, *Supporting Expeditionary Aerospace Forces: Expanded Analysis of LANTIRN Options*, Santa Monica, Calif.: RAND Corporation, MR-1225-AF, 2001. As of April 16, 2019:

https://www.rand.org/pubs/monograph_reports/MR1225.html

- As part of a larger study of support for EAFs, this report presents an analysis that addresses logistics structure alternatives for meeting demands for Low Altitude Navigation and Targeting Infrared at Night (LANTIRN) across a spectrum of operational requirements. It discusses the benefits of consolidating LANTIRN intermediate maintenance and the sensitivities to transportation delays, shortages of support equipment, and capability and risk levels that the Air Force is willing to accommodate.

Terry L. Gabreski, James A. Leftwich, Robert S. Tripp, C. Robert Roll, Jr., and Cauley Von Hoffman, "Command and Control Doctrine for Combat Support: Strategic- and Operational-Level Concepts for Supporting the Air and Space Expeditionary Force," *Air and Space Power Journal*, Vol. 17, No. 1, Spring 2003. As of April 16, 2019:

<https://www.dtic.mil/dtic/tr/fulltext/u2/a521677.pdf>

- Air and space power planning processes have improved over the past decade to provide a more efficient joint capability to joint force commanders. These improvements have caused service and joint doctrine to evolve and communicate how best to employ air and space power. The authors argue that CS doctrine has not achieved that same clarity. Instead, better integration of CS and operations planning and command and control (C2) represents a doctrinal growth area that should receive our focus as we transform the Air Force into an expeditionary, capability-based force.

Approaching CS doctrine from the same campaign-based planning mind-set as force employment offers the key to eliminating the ad hoc and inefficient nature of sustaining and supporting Air Force combat power.

Lionel A. Galway, Robert S. Tripp, John G. Drew, C. Chris Fair, and Timothy L. Ramey, “A Global Infrastructure to Support EAF,” in “Expeditionary Airpower: Part 1—A Global Infrastructure to Support EAF,” *Air Force Journal of Logistics*, Vol. XXIII, No. 2, Summer 1999. As of April 16, 2019:

<https://apps.dtic.mil/dtic/tr/fulltext/u2/a366729.pdf>

- This article discusses how expeditionary operations present numerous challenges, particularly in combat support. Analyses are presented that indicate achieving the Expeditionary Air Force (EAF) goals with current support processes requires strategic preparation of a global support infrastructure: the development of a global system of forward locations, judiciously prepositioned material, and providing other types of logistics support such as maintenance and transportation. Two key aspects of this global infrastructure: forward operating locations (FOLs) and FSLs.

Lionel Galway, Robert S. Tripp, Timothy L. Ramey, and John G. Drew, *Supporting Expeditionary Aerospace Forces: New Agile Combat Support Postures*, Santa Monica, Calif.: RAND Corporation, MR-1075-AF, 2000. As of April 16, 2019:

https://www.rand.org/pubs/monograph_reports/MR1075.html

- With the end of the Cold War, the United States has entered an entirely new security environment that has required the U.S. Air Force to stage a large number of deployments, carried out by a substantially smaller force than existed in the 1980s. To meet these challenges and to address resulting personnel turbulence, the Air Force has formulated the EAF concept (fast deployments to a breaking crisis, possibly to “bare bases” with minimal infrastructure in place). Prototype analyses in this report suggest that with today’s support processes, policies, and technologies, deploying even a modest fighter-based combat force to a bare base will

require several days of development before the FOL can sustain a high-flying tempo. Achieving the EAF goals will require strategic preparation of theater infrastructure—development of a global system of support locations (FSLs and in the continental United States [CONUS]) that provide materiel, maintenance, and transportation to deployed units at FOLs. Determining how support activities are distributed between CONUS, FSLs, and FOLs is the essence of strategic support decisions. The authors assert that these decisions require analyses carried out with a strategic perspective, one that views the entire support structure, both inside and outside CONUS, as a system of global support.

Amanda Geller, David George, Robert S. Tripp, Mahyar A. Amouze-gar, and C. Robert Roll, Jr., *Supporting Air and Space Expeditionary Forces: Analysis of Maintenance Forward Support Location Operations*, Santa Monica, Calif.: RAND, MG-151-AF, 2004. As of April 16, 2019:

<https://www.rand.org/pubs/monographs/MG151.html>

- The Air Force is reexamining its support infrastructure to focus on the goals of faster deployment, reduction in the footprint, increased flexibility, and greater personnel stability. This study examines a potential reconfiguration of the current support system: the creation of maintenance forward support locations to consolidate intermediate maintenance near, but not in, the theater of operations. Such locations are known as Centralized Intermediate Repair Facilities, or CIRFs. RAND studies found CIRF support of such commodities as F-15 avionics components, LAN-TIRN pods, and jet engines to be effective in today's Air and Space Expeditionary Force environment. RAND has also looked at potential CIRF locations, reduction of deployment footprint, and the command and control system supporting repair and other processes. The report recommends that the Air Force explore the use of CIRFs outside of the United States as well as within, establish an Operational Support Center at each Major Command, and centralize "ownership" of engines and pods. An extended analysis of centralized ownership is appended.

Amanda Geller, Robert S. Tripp, Mahyar Amouzegar, and John G. Drew, "C2 in the CIRF Test: A Proof of Concept," *Air Force Journal of Logistics*, Vol. XXVII, No. 2, Summer 2003. As of April 16, 2019: <https://www.dtic.mil/dtic/tr/fulltext/u2/a421853.pdf>

- This article focuses on three components of the ACS network: the combat support command and control (CSC2) system, maintenance FSLs, and the distribution system that connects the FSLs to the FOLs. Specifically, we discuss how a CSC2 system was implemented in a test of maintenance FSLs, more commonly known as CIRFs. The CSC2 system implemented during the CIRF test demonstrates the viability of the CSC2 process concepts outlined in the CSC2 TO-BE operational architecture.

Richard Hillestad, *Dyna-METRIC: Dynamic Multi-Echelon Technique for Recoverable Item Control*, Santa Monica, Calif.: RAND Corporation, R-2785-AF, 1982. As of April 16, 2019: <https://www.rand.org/pubs/reports/R2785.html>

- The Dyna-METRIC model was developed to study and predict the readiness of groups of aircraft squadrons as determined by a major subset of logistics resources, namely, those associated with component repair and resupply. This report describes the mathematical approaches to modeling the effects of spare parts supply, component repair, and related processes on combat capability. It does not describe the implementation of any specific version of Dyna-METRIC. Section II reviews the time-dependent pipeline equations. Section III describes time-dependent stockage and component-repair measures of performance. Section IV combines these measures to give aircraft capability measures. Section V introduces the pipeline model for indentured components, while Section VI describes the pipeline equations for the time-dependent, multiple-echelon model. Section VII describes the optimization techniques for supply requirements, and Section VIII describes the approach for limited service facilities.

Richard Hillestad, Robert Kerchner, Louis W. Miller, Adam Resnick, and Hyman L. Shulman, *The Closed-Loop Planning System for Weapon System Readiness*, Santa Monica, Calif.: RAND Corporation, MG-434-AF, 2006. As of April 16, 2019:

<https://www.rand.org/pubs/monographs/MG434.html>

- The U.S. Air Force does not have an effective way of allocating limited funding for depot-level repair across weapon systems and calculating the readiness implications of such allocations. This report describes a methodology that estimates the effect of depot repair funding allocations on aircraft availability. The methodology is called the “closed loop” planning system because it provides feedback, as opposed to the open-loop nature of the current planning system, which does not. The report describes the shortcomings in the current system to rationalize the development of the closed-loop methodology. It also illustrates the application of a prototype of the new planning system using a subset of real data from Air Force depot-level repair. It compares the cost of achieving the same level of readiness with the current Air Force approach and the closed-loop methodology. In addition, it describes extensions of the methodology that would be useful for both long-term and short-term planning.

James S. Hodges, with Raymond A. Pyles, *Onward Through the Fog: Uncertainty and Management Adaptation in Systems Analysis and Design*, Santa Monica, Calif.: RAND Corporation, R-3760-AF/A/OSD, 1990. As of April 16, 2019:

<https://www.rand.org/pubs/reports/R3760.html>

- Policy analysis has always involved great uncertainty. Tools have been available for handling some of that uncertainty, but policy analysis work in many fields has fallen into stereotyped problem formulations and analytical approaches. In particular, treatments of uncertainty are typically incomplete and often conceptually wrong. This report argues that these shortcomings produce pervasive systematic biases in analyses. It describes and discusses the common mode of policy analysis and identifies its two main shortcomings: omission of crucial sources of uncertainty and neglect of

systems' ability to respond to the unexpected. It categorizes some varieties of uncertainty relevant to policy analysis and presents examples of ways they are commonly represented. Finally, it discusses designing and evaluating systems, and presents a collection of generic strategies for uncertain situations.

Karen E. Isaacson and Patricia M. Boren, *Dyna-METRIC Version 6: An Advanced Capability Assessment Model*, Santa Monica, Calif.: RAND Corporation, R-4214-AF, 1993. As of April 16, 2019: <https://www.rand.org/pubs/reports/R4214.html>

- This report describes Version 6 of the Dyna-METRIC capability assessment model RAND developed to support logistics planning. Using information about the planned usage of aircraft, the characteristics of the aircraft components, and their demand for logistics resources, Dyna-METRIC assesses the effects of war-time dynamics, produces operational performance measures, and identifies potential problems. Version 6 improves upon earlier versions by incorporating a more fully developed representation of the repair process and its constraints. It also considers the effects of additional sources of uncertainty and some strategies that might mitigate that uncertainty. The report provides users with a comprehensive description of the model's motivation, capabilities, methodology, and use. A sample analysis based on 30 avionics components of the F-16C/D aircraft illustrates its use.

Karen E. Isaacson, Patricia Boren, Christopher L. Tsai, and Raymond A. Pyles, *Dyna-METRIC Version 4: Modeling Worldwide Logistics Support of Aircraft Components*, Santa Monica, Calif.: RAND Corporation, R-3389-AF, 1988. As of April 16, 2019: <https://www.rand.org/pubs/reports/R3389.html>

- This report describes Dyna-METRIC Version 4, a computer model that relates logistics resources and policies to wartime readiness. Developed for the use of logisticians to improve wartime logistics support, Dyna-METRIC assesses the effects of war-time dynamics and repair constraints and provides operational performance measures, problem detection, and spares require-

ments. Version 4 consists of five programs that provide for three echelons of interaction (including the depot-to-theater link) and three levels of components (for which demand processes, repair processes, and spares levels may vary). Dyna-METRIC portrays component support processes as a network of pipelines through which aircraft components flow as they are repaired or replaced within a single theater. Using the sum of all the pipeline segments, Dyna-METRIC determines the complete probability distribution for the number of parts in repair and on order. Combining the distributions for all components provides the estimate of aircraft availability and sorties.

Zalmay Khalilzad and Jeremy Shapiro, eds., with David Ochmanek, Daniel Byman, Matthew Waxman, Donald Stevens, John Gibson, Robert Preston, John C. Baker, Brian Nichiporuk, Glenn Buchan, Richard Mesic, David A. Shlapak, Robert S. Tripp, Charles Robert Roll, Jr., Lionel A. Galway, John G. Drew, Mahyar A. Amouzegar, Clifford A. Grammich, Frank Camm, Carl J. Dahlman, and David E. Thaler, *Strategic Appraisal: United States Air and Space Power in the 21st Century*, Santa Monica, Calif.: RAND Corporation, MR-1314-AF, 2002. As of April 16, 2019:

https://www.rand.org/pubs/monograph_reports/MR1314.html

- This report draws on the expertise of researchers across RAND to explore the challenges and opportunities that the U.S. Air Force faces as it strives to support the nation's interest in a challenging technological and security environment. Contributors discuss the status of modernization efforts within the Air Force, including the RAND Project AIR FORCE (PAF) vision for an evolving ACS system. This vision draws from RAND research evaluating how ACS design options affect EAF effectiveness and efficiency, and the chapter serves as a summary for many earlier monographs and reports presented in this bibliography.

Paul S. Killingsworth, Lionel A. Galway, Eiichi Kamiya, Brian Nichiporuk, Robert S. Tripp, and James C. Wendt, *Flexbasing: Achieving Global Presence for Expeditionary Aerospace Forces*, Santa Monica, Calif.: RAND Corporation, MR-1113-AF, 2000. As of April 16, 2019:

https://www.rand.org/pubs/monograph_reports/MR1113.html

- The Expeditionary Aerospace Force (EAF) will need a strategy to deploy and employ forces in the face of uncertain overseas operating locations. The authors propose that this uncertainty can be managed by actively pursuing an overseas presence strategy based on maintaining high levels of logistical and operational flexibility. They call this strategy “Flexbasing.” To leverage the advantages of aerospace power, the authors suggest establishment of a global logistics support system and provision of full-spectrum force protection for deployed forces. The Air Force should (1) establish a global system of core and forward support locations and forward operating locations; (2) maintain a robust mix of long- and short-range combat capabilities; (3) develop space as a forward support location; (4) advocate a global presence strategy as a joint initiative; (5) establish a global logistics/mobility support system for the EAF; and (6) provide full-spectrum force protection to deployed expeditionary forces. The combination of these initiatives will enable the forces to deploy to widely varying locations.

James Leftwich, Robert Tripp, Amanda Geller, Patrick Mills, Tom LaTourette, C. Robert Roll, Jr., Cauley von Hoffman, and David Johansen, *Supporting Expeditionary Aerospace Forces: An Operational Architecture for Combat Support Execution Planning and Control*, Santa Monica, Calif., MR-1536-AF, 2002. As of April 16, 2019:

https://www.rand.org/pubs/monograph_reports/MR1536.html

- As part of RAND’s work to define the elements of a combat support system to help achieve U.S. Air Force Aerospace Expeditionary Force goals, this report provides a critical analysis of the current C2 architecture for CS. Based on this analysis as well as interviews with Air Force personnel, lessons from the air war over Serbia, and doctrinal changes and evolving practices, the authors

provide a series of structural concepts to help improve execution of the C2 for combat support and remedy identified shortfalls in the current structure. The proposed architecture would allow the combat support community to quickly estimate requirements for force package options and to assess the feasibility of operational and support plans. To transition to the new architecture, the authors recommend summarizing and clarifying Air Force CS doctrine and policy on C2, using feedback to monitor performance against plans, creating standing CS organizations to promote stability in turning from one contingency to the next, cross-training operations and combat support personnel on each other's roles, and fielding improved information and decision support tools.

Kristin F. Lynch, John G. Drew, David George, Robert S. Tripp, Charles Robert Roll, Jr., and James Leftwich, *The Air Force Chief of Staff Logistics Review: Improving Wing-Level Logistics*, Santa Monica, Calif.: RAND Corporation, MG-190-AF, 2005. As of April 16, 2019: <https://www.rand.org/pubs/monographs/MG190.html>

- The USAF Chief of Staff (CSAF) directed a study of wing-level logistics processes called the Chief's Logistics Review. The purpose of the study was to identify process and training deficiencies within existing organizations that contributed to declining readiness and to evaluate potential solutions. PAF was asked, as an analytic advisor to the Air Force, to develop an analytic approach to ensure that the CSAF received all potential options and a costs/benefits analysis of each. One outcome was the need for better prepared logistic leadership at the theater and above levels.

Kristin F. Lynch, John G. Drew, Sally Sleeper, William A. Williams, James M. Masters, Louis Luangkesorn, Robert S. Tripp, Dahlia S. Lichter, and Charles Robert Roll, Jr., *Supporting the Future Total Force: A Methodology for Evaluating Potential Air National Guard Mission Assignments*, Santa Monica, Calif.: RAND Corporation, MG-539-AF, 2007. As of April 16, 2019:

<https://www.rand.org/pubs/monographs/MG539.html>

- Manpower end-strength reductions of active duty personnel in the U.S. Air Force are making it more difficult to support the air and space expeditionary force construct using current force employment practices. The Air National Guard (ANG), however, will not undergo significant manpower reductions but will be affected by plans that call for the retirement of a significant number of its aircraft, leaving it with a large number of highly trained, highly experienced personnel with no aircraft to operate and support. The authors develop a methodology to evaluate missions that could be transferred from the active component to the ANG without significant cost to the total force. They conclude that four areas—Predator operations and support, air mobility command and control, Commander of Air Force forces staffing, and base-level intermediate maintenance—are missions that could benefit from ANG assignment.

Kristin F. Lynch, John G. Drew, Robert S. Tripp, and C. Robert Roll, Jr., *Supporting Air and Space Expeditionary Forces: Lessons from Operation Iraqi Freedom*, Santa Monica, Calif.: RAND Corporation, MG-193-AF, 2005. As of April 16, 2019:

<https://www.rand.org/pubs/monographs/MG193.html>

- Since 1997, RAND has studied options for configuring an ACS system that would enable the achievement of Air and Space Expeditionary Force (AEF) goals. Operation Iraqi Freedom (OIF) offered an opportunity to examine the implementation of new ACS concepts in a wartime environment. In 2000, Project AIR FORCE helped evaluate combat support lessons from Joint Task Force Noble Anvil (JTF NA), the U.S. component of Operation Allied Force, in Serbia. In 2002, Project AIR FORCE evalu-

ated combat support lessons from Operation Enduring Freedom (OEF), in Afghanistan. Some of the concepts and lessons learned from JTF NA and OEF were implemented in supporting OIF. The report presents an analysis of combat support experiences associated with OIF, the war in Iraq, and compares these experiences with those associated with JTF NA, in Serbia, and the first 100 days of OEF. The analysis offered an opportunity to compare findings and implications from JTF NA, OEF, and OIF. Its objectives were to indicate how combat support performed in the OIF scenario; examine how ACS concepts were implemented in OIF; and compare JTF NA, OEF, and OIF experiences to determine similarities and applicability of lessons across experiences and to determine whether some experiences are unique to particular scenarios. The report focuses on experiences from OIF and what those experiences imply for combat support system design to ensure that AEF goals can be achieved. Combat support planning and execution (CSC2) processes and command and control organizational alignments have improved since JTF NA and OEF. The implementation of pieces of the future, or TO-BE, CSC2 operational architecture aided in this development, although integrating deliberate planning processes and crisis planning activities requires more work. As well, austere FOLs and an immature theater infrastructure made early planning, knowledge of the theater, and FOL preparation more important. Survey information to develop FOLs was more readily available during OIF because of other ongoing operations in the region. The Commander, Air Combat Command (ACC/CC), sponsored this research, which was conducted in the Resource Management Program of RAND's Project AIR FORCE, in coordination with the Air Force Deputy Chief of Staff for Installations and Logistics (AF/IL). The research for this report was completed in August 2003. This report should be of interest to logisticians, operators, and mobility planners throughout the Department of Defense, especially those in the Air Force.

Kristin F. Lynch, John G. Drew, Robert S. Tripp, Daniel M. Romano, Jin Woo Yi, and Amy L. Maletic, *Implementation Actions for Improving Air Force Command and Control Through Enhanced Agile Combat Support Planning, Execution, Monitoring, and Control Processes*, Santa Monica, Calif.: RAND Corporation, RR-259-AF, 2014a. As of April 16, 2019:

https://www.rand.org/pubs/research_reports/RR259.html

- There has always been disparity between the availability of combat support resources and process performance and the capabilities needed to support military operations, and the current defense environment will likely exacerbate this imbalance. Therefore, operational commanders, authorities who prioritize and allocate resources, and resource providers all need to know how combat support enterprise constraints and alternative resource allocation decisions would impact planned and potential operations and when ACS process performance breaches the control parameters set to meet contingency operation requirements. Using the vision for enhanced C2 presented in the architecture developed as a companion piece to this analysis, this report identifies and describes where shortfalls or major gaps exist between current ACS processes and the vision for integrating enhanced ACS processes into Air Force C2. It evaluates C2 nodes from the level of the President and Secretary of Defense to the units and sources of supply. It also evaluates these nodes across operational phases and suggests mitigation strategies needed to facilitate an efficient and effective global C2 network.

Kristin F. Lynch, John G. Drew, Robert S. Tripp, Daniel M. Romano, Jin Woo Yi, and Amy L. Maletic, *An Operational Architecture for Improving Air Force Command and Control Through Enhanced Agile Combat Support Planning, Execution, Monitoring, and Control Processes*, Santa Monica, Calif.: RAND Corporation, RR-261-AF, 2014b. As of April 16, 2019:

https://www.rand.org/pubs/research_reports/RR261.html

- Currently, ACS planning, execution, monitoring, and control processes are poorly integrated with operational planning processes

and have little ability to show how resource allocation decisions would impact planned and potential operations. This report presents an architecture that depicts how enhanced ACS processes could be integrated into Air Force C2 as it is defined in Joint Publications. This architecture, which focuses on the near term (the next 4–5 years) using current Air Force assets, was created by (1) evaluating previous RAND-developed operational architectures from 2002 and 2006 and (2) refining those architectures in light of the current operational and fiscal environments. It first identifies C2 processes and the echelons of command responsible for executing those processes and then describes how enhanced ACS planning, execution, monitoring, and control processes could be integrated with operational-level and strategic-level C2 processes to provide senior leaders with enterprise ACS capability and constraint information.

Kristin F. Lynch and William A. Williams, *Combat Support Execution Planning and Control: An Assessment of Initial Implementations in Air Force Exercises*, Santa Monica, Calif.: RAND Corporation, TR-356-AF, 2009. As of April 16, 2019:

https://www.rand.org/pubs/technical_reports/TR356.html

- This report provides details on a Headquarters (HQ) U.S. Air Force (USAF)/Deputy Chief of Staff for Installations and Logistics (IL) request for RAND PAF to study the current (“AS-IS”) CSC2 OA and, using the results of lessons learned during operations in Serbia in 1999 and OEF, to develop a future (“TO-BE”) C2 OA. It outlines changes in key organizations and provides observations on aspects of the TO-BE OA from its use in important CSC2 nodes during two Air Force exercises, pointing to potential productivity gains and enhanced decision-making information as the Air Force continues to implement the architecture.

Ronald G. McGarvey, Manuel Carrillo, Douglas C. Cato, Jr., John G. Drew, Thomas Lang, Kristin F. Lynch, Amy L. Maletic, H. G. Massey, James M. Masters, Raymond A. Pyles, Ricardo Sanchez, Jerry M. Sollinger, Brent Thomas, Robert S. Tripp, and Ben D. Van Roo, *Analysis of the Air Force Logistics Enterprise: Evaluation of Global Repair Network Options for Supporting the F-16 and KC-135*, Santa Monica, Calif.: RAND Corporation, MG-872-AF, 2009. As of April 16, 2019:

<https://www.rand.org/pubs/monographs/MG872.html>

- Changes in the operational environment may warrant changes in the Air Force's logistics infrastructure and concepts of operation, which are still largely based on assumptions developed during the Cold War. Recognizing the importance of the logistics enterprise, the Air Force has initiated interrelated activities to transform current logistics processes to improve support to operational units. As part of this effort, RAND was asked to undertake a comprehensive strategic reassessment of the entire Air Force logistics enterprise, examining the logistics workload, how that workload should be accomplished, and how these issues should be revisited over time. The analyses presented in this monograph show how F-16 and KC-135 aircraft maintenance units can be reconfigured to support mission generation operations, with "heavy maintenance," such as phase inspections for fighter aircraft, being provided by an enterprise network of centralized repair facilities. This approach utilizes optimization models to identify options that either exceed current maintenance capabilities at current cost levels or meet required capability levels at reduced cost.

Ronald G. McGarvey, James M. Masters, Louis Luangkesorn, Stephen Sheehy, John G. Drew, Robert Kerchner, Ben D. Van Roo, and Charles Robert Roll, Jr., *Supporting Air and Space Expeditionary Forces: Analysis of CONUS Centralized Intermediate Repair Facilities*, Santa Monica, Calif.: RAND Corporation, MG-418-AF, 2008. As of April 16, 2019:

<https://www.rand.org/pubs/monographs/MG418.html>

- This monograph describes a series of analyses performed for the United States Air Force. These analyses focused on designing a set of networks of CIRFs that would provide centralized off-equipment repair of major aircraft components in CONUS. The premise for the investigation was that well-designed CONUS CIRF networks could provide maintenance support more efficiently and effectively than traditionally used procedures, which generally rely on decentralized, maintenance facilities. Although the USAF has experience with operating CIRFs in both the CONUS and overseas, Air Force leadership did not have an analytic method for designing cost-effective CIRF networks or readily comparing alternative potential network designs. This monograph describes the new modeling approach developed to construct the CONUS CIRF network designs and presents detailed results from the specific analyses. The analyses are based on F-15, F-16, and A-10 aircraft force structure bed-downs resulting from the Defense Base Closure and Realignment Commission's 2005 recommendations. For the three aircraft types, all CONUS active duty bases, ANG installations, and Air Force Reserve Command (AFRC) installations possessing combat-coded or training aircraft, along with some Air Force Materiel Command (AFMC) bases, were used as locations to be supported by CIRF networks. CIRF network designs were constructed for aircraft engines (TF34, F100, F110), electronic warfare (EW) pods (ALQ-131, ALQ-184), LANTIRN navigation (AN/AAQ-13) and targeting pods (AAQ-14s), and F-15 avionics line replaceable units (LRUs). Tasking scenarios considered in these analyses included normal peacetime training and readiness, AEF deployment taskings, and major regional conflict (MRC) taskings.

Ronald G. McGarvey, Robert S. Tripp, Rachel Rue, Thomas Lang, Jerry M. Sollinger, Whitney A. Conner, and Louis Luangkesorn, *Global Combat Support Basing: Robust Prepositioning Strategies for Air Force War Reserve Materiel*, Santa Monica, Calif.: RAND Corporation, MG-902-AF, 2010. As of April 16, 2019:

<https://www.rand.org/pubs/monographs/MG902.html>

- The ability to rapidly deploy forces into austere locations is essential to the global power projection concept of operation. Much of the materiel used by such expeditionary forces does not deploy with the unit but is instead sourced from a global network of prepositioning storage locations, to reduce the transportation requirements associated with the movement of such materiel. Current storage concepts for prepositioned materiel are based on planning assumptions from the Cold War era: that deployment scenarios and their associated support requirements could be fairly well identified in advance and the necessary materiel prepositioned at anticipated deployment sites. This monograph identifies alternative approaches to storing combat support materiel that satisfy the requirements of deploying forces in an expeditionary environment that more closely resembles the current Department of Defense planning guidance, while simultaneously reducing total system costs and increasing robustness in the event of disruptions such as loss of access to a storage site.

Louis W. Miller and John B. Abell, *DRIVE (Distribution and Repair in Variable Environments): Design and Operation of the Ogden Prototype*, Santa Monica, Calif.: RAND Corporation, R-4158-AF, 1992.

As of April 16, 2019:

<https://www.rand.org/pubs/reports/R4158.html>

- This report describes the design and operation of a mechanism that was developed and demonstrated in prototype form at the Ogden ALC. Called DRIVE (Distribution and Repair in Variable Environments), it is the kernel of an improved approach to managing the component repair workload at ALCs. Specifically, “snapshots” of the current worldwide asset position, coupled with specified aircraft availability goals at bases and item character-

istics drawn from standard Air Force Logistics Command data systems, are used by a computer-based algorithm to prioritize component repairs and allocate the assets to locations worldwide in a way that maximizes the probability of achieving availability goals. This approach contrasts sharply with the current component repair system, in which component repairs are a matter of negotiation at the ALC, based on estimated repair requirements stated by the item manager and asset data that are six to nine months old at the time the repairs take place.

Patrick Mills, John G. Drew, John A. Ausink, Daniel M. Romano, and Rachel Costello, *Balancing Agile Combat Support Manpower to Better Meet the Future Security Environment*, Santa Monica, Calif.: RAND Corporation, RR-337-AF, 2014. As of April 16, 2019: https://www.rand.org/pubs/research_reports/RR337.html

- This research report uses an enterprise-oriented approach to assess the capacity of the current ACS manpower mix to support expeditionary operations. It assesses the costs and capacity of several rebalanced mixes that are intended to address current imbalances among its career fields relative to expeditionary demands. The analysis finds that the Air Force can achieve more expeditionary ACS capacity than it currently has by realigning manpower, and it can realize substantial savings by reducing end strength and substituting civilian billets for military billets.

Patrick Mills, Ken Evers, Donna Kinlin, and Robert S. Tripp, *Supporting Air and Space Expeditionary Forces: Expanded Operational Architecture for Combat Support Planning Execution Control*, Santa Monica, Calif.: RAND Corporation, MG-316-AF, 2006. As of April 16, 2019:

www.rand.org/pubs/monographs/MG316.html

- Anticipating varied and fast-breaking regional crises in the future, the United States is reassessing how it prepares, maintains, and employs its military forces. Key to this effort is examining the CS system, and particularly the command and control of CS forces (CSC2). This research looks at the current operational architec-

ture for incorporating CSC2 and proposes an expanded version of an architecture for the future. Using interviews with personnel, lessons learned from recent operations, and analysis of current CSC2, this report's authors make recommendations to help the Air Force's CS community move to this new architecture. This book builds on previous RAND research and is part of a larger series dedicated to bettering the support of the Air and Space Expeditionary Force. The accompanying CD-ROM contains electronic versions of detailed process diagrams and holds the complete library of notional information products the authors propose.

Patrick Mills, Muharrem Mane, Kenneth Kuhn, Anu Narayanan, James D. Powers, Peter Buryk, Jeremy M. Eckhause, John G. Drew, and Kristin F. Lynch, *Articulating the Effects of Infrastructure Resourcing on Air Force Missions: Competing Approaches to Inform the Planning, Programming, Budgeting, and Execution System*, Santa Monica, Calif.: RAND Corporation, RR-1578-AF, 2017. As of April 16, 2019: https://www.rand.org/pubs/research_reports/RR1578.html

- The Air Force civil engineering community has found that its methods for articulating infrastructure funding needs and mission impacts in the Program Objective Memorandum (POM) process are insufficient, and it is in the process of investigating alternatives. This analysis explores the relationship between Air Force infrastructure management and mission capability and risk. The goal is to identify methodological approaches and data requirements for articulating and quantifying these links and enabling the Air Force to answer the question: What is the effect of funding infrastructure below stated requirements? The authors identified three alternative approaches for answering the above question: a project scorecard approach, an approach based on mission outcome metrics, and an approach based on composite risk metrics. In this report, the authors assess the strengths, weaknesses, and relative implementation burden of each approach, and they explore ways to mitigate the weaknesses of each approach to make them most useful in the Air Force context. Finally, they

identify steps the Air Force can take to implement these concepts and to improve its ability to develop a systematic, evidence-based case for sustainment, restoration, and modernization funding within the POM process more generally.

Patrick Mills, Robert S. Tripp, James A. Leftwich, John G. Drew, Jerry M. Sollinger, and Robert G. DeFeo, *Support to the Air Force Installation and Mission Support Center: Enabling AFIMSC's Role in Agile Combat Support Planning, Execution, Monitoring, and Control*, Santa Monica, Calif.: RAND Corporation, RR-1555-AF, 2017. As of April 16, 2019:

https://www.rand.org/pubs/research_reports/RR1555.html

- The U.S. Air Force is in the midst of transforming the way ACS is managed to support training, steady state operations, and contingency operations. The reorganization of Air Force Materiel Command into the five-center construct was one significant milestone in the transformation. Another is the establishment of the Air Force Installation and Mission Support Center (AFIMSC). This report provides a strategic view of the analytical capabilities that are needed by AFIMSC to allocate resources to and assess the performance of installation and mission support activities. AFIMSC needs a coherent, rational, and transparent method to allocate resources across missions and installations. The Air Force needs a common lexicon of metrics, clear business rules, and a construct to report enterprise performance to senior leaders.

Nancy Y. Moore, Cynthia R. Cook, Clifford Grammich, and Charles Lindenblatt, *Using a Spend Analysis to Help Identify Prospective Air Force Purchasing and Supply Management Initiatives: Summary of Selected Findings*, Santa Monica, Calif.: RAND Corporation, DB-434-AF, 2004. As of April 16, 2019:

https://www.rand.org/pubs/documented_briefings/DB434.html

- This documented briefing summarizes research on how the Air Force might use an analysis of its spending to develop better supply strategies, improve its relationships with suppliers, and better manage its supply base. Best practices offer many ways by

which the Air Force can improve performance and save money. Such techniques include consolidating multiple contracts with existing providers; selecting the best providers and offering them longer contracts with broader scopes of goods and services; and working with selected strategic partners to improve quality, responsiveness, reliability, and cost. There are many challenges to conducting an Air Force-wide spend analysis, primarily the lack of detailed, centralized data on all expenditures, as well as questions about data quality for those data that are available. Nevertheless, the data that do exist point to many prospective sources of savings and performance improvements. Because the Air Force needs to balance prospective savings, performance improvements, risks, socioeconomic and other goals, and other regulations not always present in the private sector, not all best commercial practices may be appropriate for it.

T. J. O'Malley, *The Aircraft Availability Model: Conceptual Framework and Mathematics*, Washington, D.C.: Logistics Management Institute, 1983. As of April 16, 2019:

<https://apps.dtic.mil/dtic/tr/fulltext/u2/a132927.pdf>

- This report provides a complete description of the Logistic Management Institute's Aircraft Availability Model (AAM): What the model does, how it does it, and why it performs. It is written for readers with a reasonable background in probability and statistics. Familiarity with multi-echelon inventory theory is helpful but not necessary. Particularly technical material is included in the appendices to the report.

Eric Peltz, Hyman L. Shulman, Robert S. Tripp, Timothy L. Ramey, and John G. Drew, *Supporting Expeditionary Aerospace Forces: An Analysis of F-15 Avionics Option*, Santa Monica, Calif.: RAND Corporation, MR-1174-AF, 2000. As of April 16, 2019:

https://www.rand.org/pubs/monograph_reports/MR1174.html

- This report builds on earlier analyses that framed a range of general EAF support concepts and assesses how well alternative logistics processes and organizational designs meet F-15 avionics

maintenance demands across the spectrum of EAF operations. It looks at deployed intermediate maintenance capabilities and consolidated, non-deploying structure options that rely greatly on intra-theater distribution.

Raymond A. Pyles, *The Dyna-METRIC Readiness Assessment Model: Motivation, Capabilities, and Use*, Santa Monica, Calif.: RAND Corporation, R-2886-AF, 1984. As of April 16, 2019:
<https://www.rand.org/pubs/reports/R2886.html>

- Logisticians must plan, in peacetime, for wartime. This report describes a computer model, Dyna-METRIC, that can help the logistician to forecast future performance and identify wartime logistics constraints. The report discusses the model's general functional characteristics and capabilities, and a simple example is employed to demonstrate both the model's interfaces (input files and output reports) and its use in analysis, so that analysts can apply the model to specific problems.

Raymond Pyles and Robert S. Tripp, *Measuring and Managing Readiness: The Concept and Design of the Combat Support Capability Management System*, Santa Monica, Calif.: RAND Corporation, N-1840-AF, 1982. As of April 16, 2019:
<https://www.rand.org/pubs/notes/N1840.html>

- This note describes a prototype management system designed to help logistics managers assess wartime readiness and identify resources and policy changes that could dramatically improve it. The system, known as the Combat Support Capability Management System, would detect situations in which theater wartime sortie capability might be jeopardized by spare parts shortages or component repair processes, and would indicate what resources or processes most degrade that capability. In addition to describing the system, this document includes several examples of its use.

Raymond A. Pyles, Robert S. Tripp, Kristin F. Lynch, Don Snyder, Patrick Mills, and John G. Drew, *A Common Operating Picture for Air Force Materiel Sustainment: First Steps*, Santa Monica, Calif.: RAND Corporation, MG-667-AF, 2008. As of April 16, 2018:

<https://www.rand.org/pubs/monographs/MG667.html>

- This report describes a common operating picture (COP) for the Air Force materiel sustainment system (MSS) that, if implemented, would make the system more efficient and more responsive to changing operational needs. The authors discuss how this COP might be applied to depot-level repairable component sustainment to improve the overall MSS.

Timothy L. Ramey, *Lean Logistics: High-Velocity Logistics Infrastructure and the C-5 Galaxy*, Santa Monica, Calif.: RAND Corporation, MR-581-AF, 1999. As of April 16, 2019:

https://www.rand.org/pubs/monograph_reports/MR581.html

- As part of a body of research defining and evaluating the concept of Lean Logistics for the U.S. Air Force, this report considers the effects on operation of the C-5 Galaxy airlift aircraft of radically reducing the time required to move and repair aircraft components. Lean Logistics updates Air Force logistics operations by applying technology and management innovations that have proven effective in the commercial world, are relevant to the central supply problems of the Air Force and are affordable. The analysis in this study used Air Force data to drive simulations of C-5 logistics operations and considered peacetime flying programs. This study found that a high-velocity infrastructure would provide C-5 performance that is the same as or better than that provided by the current infrastructure across a wide range of conditions and circumstances. A high-velocity infrastructure would require only one-sixth the amount of inventory at one-third the cost of the current infrastructure to produce the same operational performance.

Albert A. Robbert, Lisa M. Harrington, Tara L. Terry, and Hugh G. Massey, *Air Force Manpower Requirements and Component Mix: A Focus on Agile Combat Support*, Santa Monica, Calif.: RAND Corporation, RR-617-AF, 2014. As of April 16, 2019:

https://www.rand.org/pubs/research_reports/RR617.html

- Processes for determining USAF manpower requirements vary considerably across and within a variety of workforces employed to meet Air Force missions, including ANG military personnel, civilian employees, and contractors. Distinctive processes have been developed for quantifying needs for operational, maintenance, and non-maintenance ACS workforces. This report's primary focus is on those quantitatively oriented manpower requirements processes and the extent to which they are validated, coordinated, and consistent.

John Y. Schrader, Leslie Lewis, William Schwabe, C. Robert Roll, and Ralph Suarez, *USFK Strategy-to-Task Resource Management: A Framework for Resource Decisionmaking*, Santa Monica, Calif.: RAND Corporation, MR-654-USFK, 1996. As of April 16, 2019:

https://www.rand.org/pubs/monograph_reports/MR654.html

- This report documents Phase 1 of a RAND project to provide an analytic capability to assist United States Forces, Korea (USFK) in its Planning, Programming, and Budgeting System deliberations and decisions. The goal of the study was to focus on broad strategic issues facing the command, yet to be sufficiently detailed to address specific resource allocation and program decisions. Phase 1 required the development of an analytic framework for dealing with resource issues and the identification of key USFK military and nonmilitary activities that affect USFK's resource planning and programming. The process is described in this report. Subsequent phases will develop alternative strategies for the utilization of the USFK's resources. Eventually, the analytic tools and methodologies will be instituted in the command.

Craig C. Sherbrooke, *METRIC: A Multi-Echelon Technique for Recoverable Item Control*, Santa Monica, Calif.: RAND Corporation, RM-5078-PR, 1966. As of April 16, 2019:

https://www.rand.org/pubs/research_memoranda/RM5078.html

- A description of METRIC, a mathematical model of a base-depot supply system translated into a computer program. METRIC is capable of determining base and depot stock levels for a group of recoverable items of the type that accounts for 78 percent of the Air Force's investment in spares. Designed for application at the weapon-system level, METRIC's primary aim is to optimize system performance for specified levels of system investment. This is probably the first multi-echelon, multi-item model ever proposed for Air Force implementation.

Michael F. Slay, Tovey C. Bachman, Robert C. Kline, T. J. O'Malley, and Frank L. Eichorn, *Optimizing Spares Support: The Aircraft Sustainability Model*, McLean, Va.: Logistics Management Institute, AF501MR1, October 1996. As of April 16, 2019:

<https://apps.dtic.mil/docs/citations/ADA320502>

- Modern inventory management typically relies, when possible, on quick deliveries from suppliers, and aims to carry minimal inventory. Such practices work best in managing low-cost items with stable demand and significant market size. But supporting advanced military equipment poses unique problems: small fleet sizes and low operating tempos lead to sporadic and unstable demand patterns; components are highly specialized, have limited or uncertain sources of supply, and often procurement lead-times of years. The Aircraft Sustainability Model (ASM), developed by the Logistics Management Institute for the United States Air Force, is a mathematical model that computes optimal spares mixes to support a wide range of possible operating scenarios. The ASM sizes spares levels based on desired weapon system readiness levels, rather than on supply-oriented measures, such as stock on shelf or percent of demands filled. The ASM has been used by the USAF to determine spares kits to support wartime squadron deployments; an enhanced version handles initial provisioning.

This report describes the model, the problems it was developed to solve, and the mathematical techniques it uses to solve them. It is intended for readers with some background in probability and statistics. Familiarity with multi-echelon inventory theory is not required.

Don Snyder and Patrick Mills, *Supporting Air and Space Expeditionary Forces: A Methodology for Determining Air Force Deployment Requirements*, Santa Monica, Calif.: RAND Corporation, MG-176-AF, 2004. As of April 16, 2019:

<https://www.rand.org/pubs/monographs/MG176.html>

- The Air Force's transition from a threat-based planning posture to a capabilities-based planning posture suggests the need for a means to calculate swiftly the manpower and equipment required to generate those capabilities. This report outlines a methodology for determining manpower and equipment deployment requirements. The methodology employs a prototype research tool called the Strategic Tool for the Analysis of Required Transportation (START). The START program generates lists of capability units, called Unit Type Codes, which are required to support a user-specified operation. The program also estimates materiel movement requirements to achieve initial operating capability at deployed locations. The appendix serves as a user's guide to the START program. A fully implemented tool based on this prototype should prove to be useful for both deliberate planning and crisis-action planning.

Don Snyder, Patrick Mills, Adam C. Resnick, and Brent D. Fulton, *Assessing Capabilities and Risks in Air Force Programming: Frameworks, Metrics, and Methods*, Santa Monica, Calif.: RAND Corporation, MG-815-AF, 2009. As of April 16, 2019:

<https://www.rand.org/pubs/monographs/MG815.html>

- The goal of the defense budget is to deliver a portfolio of capabilities to meet a spectrum of uncertain future security environments. This report reexamines capabilities-based programming

by introducing a new definition of capability metrics and a new set of algorithms for building and evaluating budgeting allocations.

Brent Thomas, Mahyar A. Amouzegar, Rachel Costello, Robert A. Guffey, Andrew Karode, Christopher Lynch, Kristin F. Lynch, Ken Munson, Chad J. R. Ohlandt, Daniel M. Romano, Ricardo Sanchez, Robert S. Tripp, and Joseph V. Vesely, *Project AIR FORCE Modeling Capabilities for Support of Combat Operations in Denied Environments*, Santa Monica, Calif.: RAND Corporation, RR-427-AF, 2015. As of April 16, 2019:

https://www.rand.org/pubs/research_reports/RR427.html

- This report documents the modeling framework PAF developed to analyze the support of combat operations in a denied environment. The models help illuminate combat support requirements, basing posture vulnerabilities, operational resilience, and capability trade-offs. Specifically, the modeling framework addresses four questions: (1) How does dispersed basing affect combat support resource requirements, and how many operating locations can be supported? (2) Where should combat support resources be stored and maintained to enable rapid deployment and employment of forces in the Pacific theater? (3) How vulnerable are U.S. air bases in denied environments, given current and planned capabilities? (4) What is the right mix and level of investment in active and passive defense materiel solutions to ensure resilience against a range of adversary kinetic attack strategies? The PAF framework consists of four models. The START estimates manpower and equipment requirements to support a given basing posture in a combat scenario. The RAND Overseas Basing Optimization Tool (ROBOT) identifies the least-cost allocation of war reserve materiel. The Theater Air Base Vulnerability Assessment Model (TAB-VAM) analyzes trade-offs among basing strategies, determines the effect of adversary attacks on sortie generation, and examines the effectiveness of threat mitigation options. The Theater Air Base Resiliency Optimization Model (TAB-ROM) finds the most cost-effective way to improve sortie generation against a range of enemy attack strategies for a given scenario. Together

these models can inform decisions concerning force posture, cost-asymmetric investments, and theater-shaping strategies in denied environments.

Robert S. Tripp, "Measuring and Managing Readiness: The Concept and Design of a Wartime Spares Push System," *Logistics Spectrum*, Vol. 17, No. 2, Summer 1983.

- By most counts, this CIRF test showed centralized maintenance operations to be an effective step toward a global ACS framework. The CIRF supported all deployed sorties at a reduced deployment footprint. The regional supply squadron provided responsive decision-making capability; logistics costs and requirements were reduced; and the pre-established trigger points, with few exceptions, successfully supported operations. Procedures and performance standards were established in advance, based on operational needs, and used to measure performance and guide operations throughout the test. For example, while support operations and spares inventories occasionally fell short of the standards set at the beginning of the test and necessitated loaners from other units, the ability of units to recognize when operations were falling short and provide the necessary resources demonstrates the effectiveness of the pre-established performance standards and feedback loops. However, as CIRF implementation progressed, opportunities to improve operations were uncovered. There were several instances of processes, chains of command, and information systems not being defined for situations that arose. This article details the achievements of the CIRF test.

Robert S. Tripp, "Strategies for Logistics C(3)I," *Air Force Journal of Logistics*, Spring 1987, pp. 23–29. As of April 16, 2019: https://archive.org/details/DTIC_ADA423426/page/n23

- This article presents an initial concept of operations for an AFLC Logistics Command, Control, Communications, and Intelligence (LOG C3I) system. It outlines the development approach AFLC plans to use to build this capability. The goal of the LOG C3I system is to provide information for orchestrating logistics

management systems (LMS) and AFLC infrastructure elements to meet dynamic wartime environments.

Robert S. Tripp, Mahyar A. Amouzegar, Ronald G. McGarvey, Rick Bereit, David George, and Joan Cornuet, *Sense and Respond Logistics: Integrating Prediction, Responsiveness, and Control Capabilities*, Santa Monica, Calif.: RAND Corporation, MG-488-AF, 2006. As of April 16, 2019:

<https://www.rand.org/pubs/monographs/MG488.html>

- This monograph discusses U.S. Air Force progress toward implementing sense and respond logistics or, as defined more broadly, sense and respond combat support. It describes some of the research that has been conducted on the military combat support system, focusing on improvements in prediction capability, responsiveness of supply chains, and a governing command and control system. The report identifies the elements of sense and respond combat support and shows what is necessary to use the concept within the military-specifically, the Air Force. It surveys the state of technology needed to implement the concept and identifies both the technical work that needs to be further developed and the Air Force organization most appropriate to manage the implementation. The capabilities described involve predicting what will be needed and responding quickly to anticipated or unanticipated needs. The monograph points out the need for both predictive tools and responsive systems working together. A key enabler of sense and response combat support is combat support command and control, which involves joint development of a plan in which logistics process performance and resource levels are related to desired operational effects; establishment of logistics process performance and resource-level control parameters; execution of the plan and tracking of control parameters against actual process performance and resource levels; signaling process owners when their processes lie outside control limits; and replanning logistics or operational components of the plan to mitigate the portions of the plan that are outside control limits.

Robert S. Tripp, Morton B. Berman, and Christopher L. Tsai, *The Concept of Operations for a U.S. Army Combat-Oriented Logistics Execution System with VISION (Visibility of Support Options)*, Santa Monica, Calif.: RAND Corporation, R-3702-A, 1990. As of April 16, 2019:

<https://www.rand.org/pubs/reports/R3702.html>

- This report describes a concept of operations for a decision support system intended to assist field- and wholesale-level logisticians in prioritizing repair and distribution actions for high-technology repairable items. The system recognizes that uncertainties will cause imbalances between requirements for high-tech components and their availability in both peacetime and wartime and enables logisticians to adjust their actions to compensate for unanticipated events. The system maximizes the probability of achieving specific weapon system availability goals over a given short-term horizon with available resources. Initial investigations have shown that a logistics system that couples responsive repair and distribution capabilities with such a decision support system could significantly improve weapon system availability over the current system using the same amount of stock and repair resources. The Army has developed plans to field-test the concept, which it refers to as the RBMS. RBMS has been incorporated as an element of the Strategic Logistics Program, which is aimed at modernizing the Army's Logistics Information Systems.

Robert S. Tripp, I. K. Cohen, Raymond A. Pyles, Richard J. Hillestad, Ronald W. Clarke, Stanley B. Limpert, and Suleiman K. Kasichieh, "A Decision Support System for Assessing and Controlling the Effectiveness of Multi-Echelon Logistics Actions," *Interfaces*, July–August 1991. As of April 16, 2019:

<https://pubsonline.informs.org/doi/abs/10.1287/inte.21.4.11>

- The authors designed a decision support system (DSS) to help logistics managers assess wartime readiness and to identify resource and policy changes that could improve it. The DSS, known as the weapon system management information system (WSMIS), detects situations where theater wartime aircraft sortie

capability might be jeopardized and by what resource shortages or logistics processing bottlenecks. The WSMIS is designed to distinguish between planned and actual logistics support capabilities. Typically, logistics resources are acquired, and functional processing capabilities are developed, far in advance of their actual application. As a result, many intervening factors can invalidate those support plans. WSMIS provides users with the capability to revalidate or revise those plans when needed.

Robert S. Tripp, John G. Drew, and Kristin F. Lynch, *A Conceptual Framework for More Effectively Integrating Combat Support Capabilities and Constraints into Contingency Planning and Execution*, Santa Monica, Calif.: RAND Corporation, RR-1025-AF, 2015. As of April 16, 2019:

https://www.rand.org/pubs/research_reports/RR1025.html

- Planners for contingency operations generally assume that sufficient CS resources will be available to support operational plans. This assumption carries a degree of risk: budgetary constraints, the inability to perfectly predict demands, the variability in supply processes, the possibility of multiple unplanned contingency operations taking place simultaneously, and other factors mean that there will always be imbalances between the global CS resources available and those requested to meet operational demands. Combatant commanders (CCDRs) and their component commands often lack information about global CS resource availabilities and constraints. Part of the challenge, from an Air Force perspective, is that the operations and CS communities do not have a cohesive approach (including doctrine, processes, analytic tools, training regimen, and organizations) to systematically include CS resource capabilities and constraints within the contingency planning process. Processes and assessment capabilities that relate CS resource availabilities/capabilities and constraints to operationally relevant metrics exist within some CS functional communities (e.g., munitions), but not others (e.g., impacts of casualties on operationally relevant metrics, such as sortie generation). The Air Force has not developed the processes

and tools needed to assess the impact of resource capabilities and constraints across the diverse set of CS resources and to determine the integrated impact of these capabilities or constraints on operational plans. This publication describes a conceptual framework for better integrating CS capabilities and constraints into contingency planning and execution at the global, combatant command (COCOM), component, and wing levels.

Robert S. Tripp and Mark C. Filteau, "Blueprints: Adopting a Construction Trade Approach in Designing Large Scale Management Information Systems," *Information and Management*, Vol. 13, No. 2, 1987, pp. 55–70. As of April 16, 2019:

[https://www.sciencedirect.com/journal/](https://www.sciencedirect.com/journal/information-and-management/vol/13/issue/2)

[information-and-management/vol/13/issue/2](https://www.sciencedirect.com/journal/information-and-management/vol/13/issue/2)

- In building large-scale Management Information Systems (MIS), it is not only necessary to employ a rigorous development methodology, but it is essential that the material recorded and used at each step in the design process be effectively communicated between users and developers. This paper describes a "new" method for facilitating effective communication between users and developers in the process. The method literally adapts construction blueprints to the MIS design process. The intent of these blueprints is to capture the essence of the design and facilitate communication with the users without the bulk verbiage that it takes to provide traditional written specifications. The paper shows how blueprints were used in the development and implementation of the Air Force's largest distributed processing MIS—The Requirements Data Bank (RDB)—to aid in effective communication and reduce critical design errors.

Robert S. Tripp, Lionel Galway, Paul S. Killingsworth, Eric Peltz, Timothy L. Ramey, and John G. Drew, *Supporting Expeditionary Aerospace Forces: An Integrated Strategic Agile Combat Support Planning Framework*, Santa Monica, Calif.: RAND Corporation, MR-1056-AF, 1999. As of April 16, 2019:

https://www.rand.org/pubs/monograph_reports/MR1056.html

- A key challenge facing the future Air Force is how to nearly continuously deploy relatively small-scale forces for peacekeeping and humanitarian relief missions while maintaining the capability to win major theater wars. In response to this challenge, the Air Force has developed the concept of an Expeditionary Aerospace Force (EAF) to deal with the range of expected missions. The report argues that this new concept requires a complete reexamination of the combat support system, especially the planning framework for combat support. This framework must integrate logistics, mobility, and operational planning across echelons, commands, and phases of warfare. The report discusses how integrated ACS planning aimed at mid-term or strategic decisions can enhance the effectiveness and efficiency of EAF operations. The authors provide an example of use of the ACS planning framework to evaluate support alternatives for a strike AEF deployment to Southwest Asia, addressing aviation support, repairable avionics components, and munitions.

Robert S. Tripp, Lionel A. Galway, Timothy Ramey, Mahyar A. Amouzegar, and Eric Peltz, *Supporting Expeditionary Aerospace Forces: A Concept for Evolving to the Agile Combat Support/Mobility System of the Future*, Santa Monica, Calif.: RAND Corporation, MR-1179-AF, 2000. As of April 16, 2019:

https://www.rand.org/pubs/monograph_reports/MR1179.html

- The Air Force is reorganizing into an Expeditionary Aerospace Force (EAF) with the goal of replacing the forward presence of aerospace power with a force that can deploy quickly in a crisis, commence operations immediately upon arrival, and sustain operations as appropriate. The success of the EAF will largely depend on the effectiveness of the ACS and mobility systems. With today's

support processes, policies, and technologies, deploying even a modest fighter-based combat force to a bare base will require several days of development before the base can sustain a high-flying tempo. Thus, resources should be prepositioned, either at the base or at a regional support facility. This report presents a framework for an integrated ACS and mobility planning process, including the ability of ACS and mobility postures to meet defense needs as they evolve. The two imperatives of global planning and evolving planning will require centralized planning, in which political, effectiveness, and cost trade-offs are made for the system as a whole so that each theater is supported and protected.

Robert S. Tripp, Lionel A. Galway, Timothy L. Ramey, Paul S. Killingsworth, John G. Drew, and C. Chris Fair, "Strategic EAF Planning—Expeditionary Airpower Part 2," in "Expeditionary Airpower: Part 2—EAF Strategic Planning," *Air Force Journal of Logistics*, Vol. XXIII, No. 3, Fall 1999. As of April 16, 2019:

https://ia802803.us.archive.org/29/items/DTIC_ADA369491/DTIC_ADA369491.pdf

- This article, Part 2, describes specific elements of an ACS planning framework for the Expeditionary Air Force (EAF). Those elements are: (1) A closed-loop strategic ACS planning process to develop alternative strategic ACS designs for future EAF concepts; (2) Use of employment driven end-to-end requirements generation models to specify requirements as a function of operational requirements and logistics policies; (3) Use of support option assessment models to compare alternative approaches and their metrics; (4) Use of an integration model for integrated commodity ACS structures and processes evaluation; (5) Evaluation of impacts of uncertainty and alternative transition paths Major Theater War (MTW) operations; (6) Use of measurements and assessments of actual process performance and resource levels; and (7) Designation of ACS planning and assessment responsibilities to direct/advocate strategic system design and evolution.

Robert S. Tripp, Kristin F. Lynch, John G. Drew, and Edward W. Chan, *Supporting Air and Space Expeditionary Forces: Lessons from Operation Enduring Freedom*, Santa Monica, Calif.: RAND Corporation, MR-1819-AF, 2004. As of April 16, 2019:

https://www.rand.org/pubs/monograph_reports/MR1819.html

- Since 1997, RAND has studied options for configuring a future ACS system that would enable AEF goals to be achieved. OEF, in Afghanistan, offered an opportunity to examine the implementation of new ACS concepts in a contingency environment. In 2000, Project AIR FORCE helped evaluate combat support lessons from JTF NA, the U.S. component of Operation Allied Force (OAF), in Serbia. (Joint Task Force Noble Anvil was the organization overseeing U.S. forces involved in OAF. This report concentrates on Air Force operations conducted by Joint Task Force Noble Anvil.) Some of the concepts and lessons learned from JTF NA were implemented in supporting OEF. *Supporting Air and Space Expeditionary Forces: Lessons from Operation Enduring Freedom* presents an analysis of combat support experiences associated with Operation Enduring Freedom and compares these experiences with those associated with Operation Allied Force. The analysis offered an opportunity to compare findings and implications from JTF NA and OEF. Its objectives were to indicate the performance of combat support in OEF, examine how ACS concepts were implemented in OEF, and compare JTF NA and OEF experiences to determine similarities and applicability of lessons across experiences and to determine whether some experiences are unique to particular scenarios. This analysis concentrates on U.S. Air Force operations in support of OAF—specifically, Joint Task Force Noble Anvil and the first 100 days of OEF. The report focuses on experiences from OEF and what those experiences imply for a combat support system designed to ensure that AEF goals can be achieved. It does not address other portions of the War on Terrorism, such as Homeland Defense (for example, Operation Noble Eagle). Both JTF NA and OEF illustrate, among other things, that more attention should be focused on political agreements and engagement policies required to develop

forward operating locations. As well, in many cases in JTF NA and OEF, the current resource-usage factors are more demanding than the assumptions used to fund resources--an imbalance that creates resource shortages that occur in contingency operations.

Robert S. Tripp, Kristin F. Lynch, John G. Drew, and Robert G. DeFeo, *Improving Air Force Command and Control Through Enhanced Agile Combat Support Planning, Execution, Monitoring, and Control Processes*, Santa Monica, Calif.: RAND Corporation, MG-1070-AF, 2012. As of April 16, 2019:

<https://www.rand.org/pubs/monographs/MG1070.html>

- Today's defense environment is particularly challenging because (1) significant portions of the force are continuously engaged in a variety of operations, ranging from active combat to humanitarian assistance, over wide geographical areas where the needs for force projection are often difficult to predict, and (2) there is increasing pressure to operate more efficiently. And, although there has always been the need to relate combat support resource requirements to operational objectives, today's environment requires quick combat support actions to tailor deployable support packages and sustainment actions to meet specific operational needs. Furthermore, economic pressures are likely to continue and could result in further reductions in resources that are set aside to meet contingency operations. In addition to economic pressures, the inability to perfectly predict resource demands, the need to shift funding from one category to another to meet unanticipated needs, and the occurrence of unanticipated world events that require intervention contribute to having imbalances between needed ACS resources and those that are available at any given time to simultaneously meet all requirements for contingency and training operations. This monograph describes ACS process gaps and recommends implementation strategies to facilitate changes needed to improve Air Force command and control through enhanced ACS planning, execution, monitoring, and control processes. The authors recommend a standardized, repeatable process to plan, execute, and control combat support

activities focused on operationally relevant metrics; reliance on global managers to identify enterprise capabilities and constraints and relay them to component numbered Air Force staffs for use in their contingency planning and execution actions; and processes for determining which combatant commanders' operations will have priority.

Robert S. Tripp, Kristin F. Lynch, Shawn Harrison, John G. Drew, and Charles Robert Roll, Jr., *Space Command Sustainment Review: Improving the Balance Between Current and Future Capabilities*, Santa Monica, Calif.: RAND Corporation, MG-518-AF, 2007. As of April 16, 2019:

<https://www.rand.org/pubs/monographs/MG518.html>

- The ability to access and continuously operate in space is vital to the economic, social, and military interests of the United States. In part because of sometimes-conflicting demands and in part because space systems are highly specialized, sustainment can be a challenge. To help Air Force Space Command (AFSPC) meet this challenge, the authors used a strategies-to-tasks framework to examine AFSPC sustainment as a whole, working toward a commandwide philosophy for space system support. The core of the philosophy is separation of demand-side, supply-side, and integrator processes and clear definition of roles and responsibilities at all levels of the command. Its adoption can provide a basis for enhancing processes, force development, doctrine, information systems, and organization across the command that can be sustained over time and through many leadership changes. The authors illustrate the implementation and benefits using specific systems and units, some of which have already demonstrated elements of this philosophy.

Robert S. Tripp, Kristin F. Lynch, Ronald G. McGarvey, Don Snyder, Raymond A. Pyles, William A. Williams, Charles Robert Roll, Jr., *Strategic Analysis of Air National Guard Combat Support and Reachback Functions*, Santa Monica, Calif. RAND Corporation, MG-375-AF, 2006. As of April 16, 2019:

<https://www.rand.org/pubs/monographs/MG375.html>

- VANGUARD is the ANG long-range transformation program. It calls for the ANG to evaluate new concepts, prepare for new missions, and adopt a new culture that capitalizes on ANG strengths and ensures that the ANG continues to add value as warfighters and to warfighters in the future while remaining ready, reliable and accessible. One way to support warfighting and warfighters is to continue to support the AEF, a concept developed by the Air Force to allow quick response, when appropriate, to national security interests with a tailored, sustainable force. The ANG already plays an important role in the AEF during wartime operations. This monograph evaluates options for Air National Guard combat support and reachback missions in four Air Force mission areas to support the AEF, investigates transformational opportunities for the ANG that would add the most value in achieving the desired operational effects, and considers how changes in unit and above-unit policies are likely to affect Total Force capabilities. It should be of interest to logisticians, operators, and mobility planners throughout the Department of Defense, especially those in the Air National Guard and active Air Force.

Robert S. Tripp, Kristin F. Lynch, Charles Robert Roll, Jr., John G. Drew, and Patrick Mills, *A Framework for Enhancing Airlift Planning and Execution Capabilities Within the Joint Expeditionary Movement System*, Santa Monica, Calif.: RAND Corporation, MG-377-AF, 2006. As of April 16, 2019:

<https://www.rand.org/pubs/monographs/MG377.html>

- Recent operations abroad have shed light on shortfalls in the way the Air Force performs intratheater airlift within the military joint end-to-end multimodal movement system. Cargo backlogs, insufficient methods of tracking cargo, inefficient use

of airlift resources, and a lack of discipline in requesting airlift support were among the problems identified. Using an expanded strategies-to-tasks framework as a “lens” for evaluating intra- and intertheater movement, the authors assess current intra-theater airlift processes, organizations, doctrine, training, and systems. The report catalogues identified shortfalls and recommends options for improving the Theater Distribution System. They recommend a clear separation of supply, demand, and integrator roles, and they provide several organizational options. They also suggest the adoption of a closed-loop planning and execution process that focuses on the trade-offs in effectiveness and efficiency of alternative network options.

Robert S. Tripp, Kristin F. Lynch, Daniel M. Romano, William Shelton, John A. Ausink, Chelsea Kaihoi Duran, Robert G. DeFeo, David W. George, Raymond E. Conley, Bernard Fox, and Jerry M. Sollinger, *Air Force Materiel Command Reorganization Analysis: Final Report*, Santa Monica, Calif.: RAND Corporation, MG-1219-AF, 2012. As of April 16, 2019:

<https://www.rand.org/pubs/monographs/MG1219.html>

- Directives from the Office of the Secretary of Defense mandating reductions in operations and maintenance staffing levels led AFMC to reexamine how it operates; the command published the plan for its proposed reorganization in November 2011. In response, the National Defense Authorization Act for Fiscal Year 2012 directed the Secretary of the Air Force to have a federally funded research and development center provide an independent review of the proposed reorganization. In January 2012, RAND Project AIR FORCE was tasked to conduct this review, the purpose of which was to describe the functional responsibilities, manpower authorizations, and disposition of AFMC’s proposed restructure, including an assessment of life-cycle costs; to independently assess how realignments would likely affect life-cycle management, weapon system sustainment, and support to the warfighter; and to examine options for providing effective and efficient weapon system life-cycle management. The resulting

analysis was limited to how the reorganization would affect product development/support-system design and operations support (depot maintenance and Air Force supply chain operations). It did not examine how the reorganization affects the management of nuclear weapons, developmental testing, or laboratory and basic research. For context, the report also includes a comprehensive overview of the history of Air Force life-cycle management and the changing roles and responsibilities of the organizational precursors to AFMC.

Robert S. Tripp, Ronald G. McGarvey, Ben D. Van Roo, James M. Masters, and Jerry M. Sollinger, *A Repair Network Concept for Air Force Maintenance: Conclusions from Analysis of C-130, F-16, and KC-135 Fleets*, Santa Monica, Calif.: RAND Corporation, MG-919-AF, 2010. As of April 16, 2019:

<https://www.rand.org/pubs/monographs/MG919.html>

- For more than 15 years, the U.S. Air Force has been continually engaged in deployed operations in Southwest Asia and in other locations. Recent Office of the Secretary of Defense planning guidance directs the services to plan for high levels of engagement and deployed operations, although their nature, locations, durations, and intensity may be unknown. Recognizing that this new guidance might impose different demands on the logistics system, senior Air Force logistics leaders asked RAND Project AIR FORCE to undertake a logistics enterprise analysis. This analysis aims to identify and rethink the basic issues and premises on which the Air Force plans, organizes, and operates its logistics enterprise. This monograph synthesizes the results of the initial phases of the logistics enterprise study. It describes an analysis of repair network options to support three series of aircraft: C-130, KC-135, and F-16. It assesses the effect of consolidating certain scheduled maintenance tasks and off-equipment component repair at centralized repair facilities. It also discusses an initial assessment of maintenance concepts that integrate wing-level and depot-level maintenance processes. Consolidated wing-level scheduled inspections and component back-shop maintenance

capabilities would be more effective and efficient than the current system, in which every wing has significant maintenance capabilities to accomplish these activities.

Robert S. Tripp, Patrick Mills, Amanda Geller, C. Robert Roll, Jr., Cauley von Hoffman, David L. Johansen, and James A. Leftwich, "Combat Support C2 Architecture," *Air Force Journal of Logistics*, Vol. XXVII, No. 2, Summer 2003. As of April 16, 2019:

<https://www.dtic.mil/dtic/tr/fulltext/u2/a421853.pdf>

- The shift toward expeditionary operations presents numerous challenges, particularly in CS. To meet these challenges, the Air Force requires a global CS infrastructure. RAND and Air Force Logistics Management Agency (AFLMA)—partnered analyses offer recommendations for such an infrastructure, which include developing FOLs from which missions are flown, FSLs and CSLs, regional repair and storage facilities, a transportation system for distribution, and a combat support command and control (CSC2) system.

Robert S. Tripp, John M. Pearson, and Larry B. Rainey, "A Small-Scale Demonstration of Cybernetic Technology and its Application to the Air Force Logistics Command (AFLC) Command, Control, Communications and Intelligence System," *Cybernetics and Systems*, Vol. 19, 1988, pp. 441–471. As of April 16, 2019:

<https://www.tandfonline.com/doi/abs/10.1080/01969728808902179>

- This article discusses the AFLC C3I system as a specific instance and discusses the importance of the application of it to AFLC. The authors discuss C3I systems in a cybernetic model context and present the system analysis (and synthesis) steps involved in designing an AFLC C3I system from a cybernetic perspective.

Robert S. Tripp and Raymond Pyles, "Measuring and Managing Readiness: An Old Problem—A New Approach," *Air Force Journal of Logistics*, Spring 1983. As of April 16, 2019:

https://archive.org/details/DTIC_ADA423185/page/n1

- This article focuses on three components of the ACS network: the CSC2 system, maintenance FSLs, and the distribution system

that connects the FSLs to the FOLs. Specifically, we discuss how a CSC2 system was implemented in a test of maintenance FSLs, more commonly known as CIRFs. The CSC2 system implemented during the CIRF test demonstrates the viability of the CSC2 process concepts outlined in the CSC2 TO-BE operational architecture. The CSC2 system is a pivotal element of the expeditionary concept, as it is responsible for coordinating the other components of the CS network. Joint and Air Force doctrine defines C2 as “the exercise of authority and direction by a properly designated commander over assigned and attached forces in the accomplishment of the mission.” 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 command and control across the range of military operations.

Robert S. Tripp and Larry Bruce Rainey, “Cybernetic Approach for the Design and Development of Management Information and Control Systems (MICS): An Illustration Within the Air Force Logistics Command,” *Cybernetica*, No. 4, January 1983, pp. 281–305. As of April 16, 2019:

https://www.researchgate.net/publication/321296092_CYBERNETIC_APPROACH_FOR_THE_DESIGN_AND_DEVELOPMENT_OF_MANAGEMENT_INFORMATION_AND_CONTROL_SYSTEMS_MICS_AN_ILLUSTRATION_WITHIN_THE_AIR_FORCE_LOGISTICS_COMMAND

- It is shown how cybernetic concepts can be used to guide Management Information and Control System (MICS) design and development activities. It is demonstrated how a cybernetic model of the organization can be used to diagnose potential problems in existing MICSs and serve to guide MICS development activities. For illustrative purposes, a case study of the AFLC is used to demonstrate how the cybernetic model can be made operational in the real world. This methodology can be used as a road map

for integrating and guiding several MICS initiatives which are underway to make AFLC more responsive in meeting potential wartime scenarios. AFLC mission responsibilities are described, and some current AFLC MICS problems are identified. Observations which can be used to guide current and future MICS design and development efforts are considered.

Robert S. Tripp and Larry B. Rainey, "The Development of a Combat Analysis Capability for the Air Force Logistics Command," *Air Force Journal of Logistics*, Vol. 8, No. 1, Winter 1984.

- This article discusses the AFLC prototype Combat Analysis Capability (CAC) established to provide the ALC commander with a predictive capability that will demonstrate weapon system impacts of alternative spares support policies and resource levels. It is designed to enhance System Program Manager (SPM) effectiveness and improve support available to the major commands (MAJCOMs). The CAC program, if successful, could be expanded to include other logistics resources and processes. The prototype CAC has been built around previous work done with the RAND Corporation to determine the payoffs of increasing SPM responsibilities in the spares area and to identify the types of information needed to achieve those payoffs.

Robert S. Tripp and Larry B. Rainey, "A Cybernetic Approach to Meaningful Measures of Merit," *Cybernetics and Systems*, Vol. 17, No. 2, 1986a.

- A cybernetic conceptual framework for the Meaningful Measures of Merit (M) program as it is proposed for AFLC is discussed.

Robert S. Tripp and Larry B. Rainey, "Design of a Control Room for the Air Force Logistics Command (AFLC), Command, Control, and Communication and Intelligence (CI) System," *Cybernetics and Systems*, Vol. 17, January 1986b. As of April 16, 2019:

https://www.researchgate.net/publication/238181764_DESIGN_OF_A_CONTROL_ROOM_FOR_THE_AIR_FORCE_LOGISTICS_COMMAND_lparAFLC_COMMAND_CONTROL_AND_COMMUNICATION_AND_INTELLIGENCE_CI_SYSTEM

- This paper discusses the importance of cybernetic and human factors engineering control room concepts and their relationship to the design and operation of the AFLC Command, Control, Communications, and Intelligence (CI) system. This paper is organized in sections which: (1) discuss control room concepts and relate their importance to CI operations; (2) describe AFLC's current CI "control room" operations (the AFLC Command Post) and associated problems; and (3) provide a suggested design for the AFLC CI control room including some information displays.

Robert S. Tripp, Larry B. Rainey, and John M. Pearson, "The Use of Cybernetics in Organizational Design and Development: An Illustration Within Air Force Logistics Command," *Cybernetics and Systems*, Vol. 14, No. 2–4, 1983, pp. 293–314. As of April 16, 2019:

<https://www.tandfonline.com/doi/abs/10.1080/01969728308927729?journalCode=ucbs20>

- The purpose of this paper is to show how cybernetic concepts can be used to guide organizational design and development activities. The intent of the paper is to demonstrate how a cybernetic model of a viable organization can be used to diagnose potential problems in existing organizations and serve to guide organizational development activities. For illustrative purposes, a case study of the AFLC is used to demonstrate how the cybernetic organizational model can be made operational in the "real world." The paper is designed to show how this methodology can be used as a road map for integrating and guiding several initiatives which are underway to make AFLC more responsive in meeting

potential wartime scenarios. This paper is organized in sections which: (1) describe AFLC mission responsibilities and organization; (2) identify current major problems; (3) describe and use a cybernetic organizational model to diagnose causes of current problems; and (4) develop some observations which can be used to guide future organizational design and development efforts.

Robert S. Tripp and C. Robert Roll, Jr., *A Framework for Evolving Agile Combat Support Concepts to Meet NATO Reaction Air Force Operational Requirements*, Santa Monica, Calif.: RAND Corporation, P-8052, 2000. As of April 16, 2019:

<https://www.rand.org/pubs/papers/P8052>

- This paper presents a framework that could be used in evolving the ACS and mobility systems of participating partners to meet the operational needs of the North Atlantic Treaty Organization (NATO) Reaction Air Force (RAF). The paper incorporates some USAF EAF results in using the framework as relevant for the NATO RAF. The paper also discusses impediments to using this framework and evolving an effective coalition ACS system.

Robert Tripp, C. Robert Roll, Jr., Lionel Galway, Timothy Ramey, John Drew, Mahyar Amouzegar, and Clifford Grammich, "A Vision for an Evolving Agile Combat Support System," in Zalmay Khalilzad and Jeremy Shapiro, eds., *Strategic Appraisal: United States Air and Space Power in the 21st Century*, Santa Monica, Calif.: RAND Corporation, MR-1314-AF, 2002, pp. 377–395. As of April 16, 2019:

https://www.researchgate.net/publication/245136187_Chapter_Ten_A_VISION_FOR_AN_EVOLVING_AGILE_COMBAT_SUPPORT_SYSTEM

- This article discusses and offers a vision of what the future ACS system might look like and how it could help the Air Force meet EAF operational goals. This vision draws from ongoing RAND research evaluating how ACS design options affect EAF effectiveness and efficiency. The system will have to support EAF operations ranging from MTWs to small-scale contingencies to peacekeeping missions. This section describes basic elements for a

system the authors believe would meet EAF operational requirements. They suggest the ACS system will need to be a global network comprising the following: FOLs, with resource allocations that support differing employment timelines; FSLs, with differing support processes and resources; and CONUS support locations (CSLs). These infrastructure elements will need to be connected by a logistics command and control system and by a very responsive distribution system to ensure that support resources arrive as combat commanders need them.

Robert S. Tripp, C. Robert Roll, Jr., and Cauley von Hoffman, "Combat Support C2 Nodes," *Air Force Journal of Logistics*, Vol. XXVII, No. 2, Summer 2003. As of April 16, 2019:
<https://www.dtic.mil/dtic/tr/fulltext/u2/a421853.pdf>

- This article presents a TO-BE combat support command and control (CSC2) operational architecture that would help the Air Force meet its AEF operational goals. The future architecture would: (1) Enable the CS community to quickly estimate requirements for force package options needed to achieve desired operational effects and assess the feasibility of operational and support plans; (2) Quickly determine beddown capabilities, facilitate rapid time-phased force deployment data (TPFDD) development, and configure a distribution network to meet employment time lines and resupply needs; (3) Facilitate execution resupply planning and performance monitoring; (4) Determine impacts of allocating scarce resources to various combatant commanders; and (5) Indicate when CS performance deviates from the desired state and implement re-planning and get-well planning analysis.

Robert S. Tripp and Carol L. Schweiger, "Displaying Combat Capability for Decision-Makers: The AFLC Sustainability Assessment Module," *Air Force Journal of Logistics*, Vol. 9, No. 4, Fall 1985. As of April 16, 2019:
https://archive.org/details/DTIC_ADA423180/page/n25

- This article covers the demonstrated interface between the Sustainability Assessment Module (SAM) of AFLC Command, Con-

trol, and Communications system and the Inter-site Command Post Communications Network (ICPCN) to present information vital to the overall assessment of weapon system sustainability. The design intent is to facilitate decision-making in the areas of planning, assessment, and monitoring.

Christopher L. Tsai, Patricia M. Boren, and Robert S. Tripp, *An Initial Evaluation of the VISION Assessment System: Its Relevance and Application to National-Level Sustainment Planning*, Santa Monica, Calif.: RAND Corporation, R-4182-A, 1992. As of April 16, 2019: <https://www.rand.org/pubs/reports/R4182.html>

- This report documents the demonstration of a prototype decision support system for logisticians called the VISION Assessment System, or VAS. The system aims to help logistics planners evaluate and improve equipment sustainability. To demonstrate the prototype, we developed a scenario involving M1 tanks similar to one that occurred during the buildup phase of Operation Desert Shield. In addition to the standard support concept, we evaluated three other strategies designed to improve tank availability: expedited requisitions, forward-deployed depot repair, and asset prioritization. The evaluation indicated that, under the standard support concept, the number of operational tanks would decline to unacceptably low levels and each enhancement strategy improved things, albeit not always to the extent anticipated. Beyond demonstrating that the prototype could address logistical questions, the project illuminated some data and usability issues. A fair amount of the data needed by VAS resides in Army standard systems, but they are not always accessible. Other elements do not exist. Also, although VAS functions, it would require additional work to make it a helpful tool at the everyday working level.

Christopher L. Tsai, Robert S. Tripp, and Morton B. Berman, *The VISION Assessment System: Class IX Sustainment Planning*, Santa Monica, Calif.: RAND, R-3968-A, 1992. As of April 16, 2019: <https://www.rand.org/pubs/reports/R3968.html>

- This report describes the underlying motivation, characteristics, and possible applications of the VISION (Visibility of Support Options) Assessment System, a decision support system designed to improve the ability of Army logisticians to address three issues that are fundamental to Class IX (spare parts) sustainment planning: (1) assessing whether the logistics system can support operational needs and objectives throughout the course of a planned conflict, (2) determining where and when problems are likely to emerge and how serious they are likely to be, and (3) identifying what can be done beforehand to avoid or mitigate those potential problems. Among the potential uses of the VISION Assessment System, the authors identify (1) assessing and improving the supportability of existing operation plans (OPLANs), (2) evaluating and choosing among alternative courses of action during OPLAN development, (3) identifying effective peacetime strategies for overcoming potential wartime problems, (4) examining new concepts and establishing new doctrine, (5) exploring cost-reduction strategies and weighing trade-offs among different resources, and (6) reporting unit sustainability.

Ben D. Van Roo, Manuel Carrillo, John G. Drew, Thomas Lang, Amy L. Maletic, Hugh G. Massey, James M. Masters, Ronald G. McGarvey, Jerry M. Sollinger, Brent Thomas, and Robert S. Tripp, *Analysis of the Air Force Logistics Enterprise: Evaluation of Global Repair Network Options for Supporting the C-130*, Santa Monica, Calif.: RAND Corporation, TR-813-AF, 2011. As of April 16, 2019: https://www.rand.org/pubs/technical_reports/TR813.html

- The U.S. Air Force has been continually engaged in deployed operations in Southwest Asia and in other locations since the 1990s. Recent Office of the Secretary of Defense planning guidance directs the services to plan for continued engagement at high levels, although their nature, locations, durations, and intensity

may be unknown. Air Force senior leaders recognized that the new guidance might impose different demands on the Air Force's logistics system, so they asked RAND Project AIR FORCE to undertake a logistics enterprise analysis. This technical report describes the benefits of reallocating certain maintenance activities between mission-generation locations and a repair network to support the C-130 fleet and consolidating repair network activities to centralized repair facilities. The report also provides an initial assessment of maintenance concepts that integrate wing-level and depot-level maintenance processes. The authors found that consolidating wing-level scheduled inspections and component back-shop maintenance capabilities provides efficiency and effectiveness gains to the C-130 maintenance network and that integration of wing-level and depot level activities may provide further gains.

Michael E. Zettler, "The New Vision," in Special Edition: "Combat Support Command and Control: A New Vision for Global Support," *Air Force Journal of Logistics*, Vol. XXVII, No. 2, Summer 2003. As of April 16, 2019:

<https://apps.dtic.mil/dtic/tr/fulltext/u2/a421853.pdf>

- This article briefly summarizes the request of the Air Force Deputy Chief of Staff, Installations and Logistics (Lieutenant General Michael E. Zettler), RAND Project Air Force (PAF) and AFLMA that began an in-depth analysis of the Combat Support Command & Control (CSC2) system in October 2000. In this work, concepts are presented for guiding the development of architecture for CS execution planning and control activities within an integrated operations and CSC2 framework. CSC2 is used as a shortened name but stress that this architecture is part of the integrated operations and CS framework. This architecture is intended for use in transforming the current Air Force CSC2 system into one more capable of supporting expeditionary forces.