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Coupling Logistics to Operations to Meet Uncertainty and the Threat (CLOUT)

An Overview

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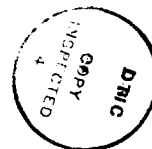
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A Project AIR FORCE Report
Prepared for the United States Air Force

RAND

PREFACE

This report provides an overview of a RAND project entitled "Enhancing the Integration and Responsiveness of the Logistics Support System to Meet Peacetime and Wartime Uncertainties," popularly known as the "Uncertainty Project." The Uncertainty Project was concerned primarily with quantifying the magnitude and pervasiveness of uncertainty in the demands for resources in peacetime and war, and developing and evaluating initiatives to cope with it. It pursued the concept that uncertainties could typically best be met by designing a responsive support system—one that, by taking management actions, could respond to unanticipated events in "near real time."

At RAND there has been increasing interest in state-of-the-world uncertainties as distinct from statistical uncertainties. For example, in RAND's Arroyo Center, which supports the U.S. Army, a study and depot demonstration effort has been undertaken covering much of the material discussed here. Projects dealing with the effect of uncertainties on munitions requirements and distribution have also been initiated.

This report should be of general interest to policymakers, policy analysts, resource managers, and those persons engaged in the further development and implementation of the Air Force's new Logistics Concept of Operations.

SUMMARY

The research described in this report was designed to:

- Understand better the magnitude and extent of variability in peacetime demands for logistics resources.

- Develop and evaluate initiatives for increasing the flexibility, robustness, and responsiveness of the logistics system at both the base/theater and depot levels to increase readiness and sustainability in the face of the unpredictability of peacetime and wartime resource demands.

- Define the need for a means by which the infrastructure should be tasked to support the "real-time" needs of the combat forces (Log C^3).

TAKING EXPLICIT ACCOUNT OF UNCERTAINTY

Uncertainty is of essentially two kinds: (a) *statistical* uncertainty, defined as variability observed in repeatable phenomena, and (b) *state-of-the-world* uncertainty, defined as uncertainty about phenomena that are not repeatable, not observed or observable, or both.[1] Planning for wartime is fraught with uncertainty of the latter kind; in fact, state-of-the-world uncertainty can fairly be said to dominate the wartime scenario. It affects peacetime planning as well. State-of-the-world uncertainty is fundamentally different from the statistical type; the variability involved is literally impossible to predict. Yet in problems involving state-of-the-world uncertainty, analysts have traditionally retreated to analytic methods intended to deal with statistical uncertainty, the methods with which they are competent and comfortable. As a result, planning efforts may ignore a wide range of possible outcomes.

Analysis of the demand for avionics spare parts demonstrates that this is true for Air Force logistics planning. In both planning and execution, support systems implicitly assume a level of predictability in resource demands that does not often exist in peacetime and almost certainly will not exist in war.[2] In peacetime, the actual range of demands experienced for certain spares is several times as large as

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[1]Hodges and Pyles, pp. 8–14.

[2]See Crawford, Gordon B., *Variability in the Demands for Aircraft Spare Parts: Its Magnitude and Implications*, RAND, R-3318-AF, January 1988.

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the range our planning procedures assume—so large that buying sufficient spares to meet the potential demand is prohibitively expensive. Such uncertainty about the future is often ignored in our planning for wartime as well. The very use of a single wartime planning scenario implicitly denies that we have great uncertainty about such important factors as the level of activity; the impact of these activities on the demands for resources; force beddown; mission mix; damage to spares, repair, and personnel resources in base attacks; the system disruptions that seem almost inevitable in wartime; and all of the other surprises the enemy is likely to induce.[3] During execution, however, circumstances in wartime may shift from state-of-the-world uncertainty to statistical uncertainty. In such a case, it may be possible to forecast demands over short periods of time.

RESPONDING TO UNCERTAINTY

This situation suggests a general class of support strategies in planning both for peacetime and, particularly, for war—strategies that account for uncertainty. One central consideration is response time. Response time can mean the sum of any of repair times, processing and handling times, order-and-ship times, transportation times, or even communication times in particular applications. The longer the response time, the more decisionmaking depends on forecasting future events. At the present time, the anticipated scenarios we need to use in planning are not likely to eventuate as predicted; thus, the more quickly the system can respond to urgent, unanticipated needs, the less vulnerable it will be to uncertainty and the more robust its performance will be in the face of it.

Even when an advanced priority system is used in peacetime depot-level repair, long response times (from 20 to 50 days, where the longest times are associated with bases with wartime deployment tasking and war reserve spares kits) force the system to rely to an undesirable extent on forecasts, which in turn are vulnerable to uncertainty. Thus it is desirable to reduce response times to a few days, a dramatic reduction to be sure, and difficult to achieve, but desirable given the problems in predicting events over long planning horizons. In fact, a very responsive system may be able to operate satisfactorily in a reactive mode so that the need for being proactive is reduced.

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[3]See Stockfisch, J. A., *Linking Logistics and Operations: A Case Study of World War II Air Power*, RAND, N-3200-AF, 1991.

There are some logistics planning problems whose implicitly long planning horizons may not be tractable to change. The problem of estimating the best mix of spares procurements is one such example. Because of the relatively long planning horizon, alternative strategies for hedging against incorrect forecasts are needed.[4]

Finally, the magnitude and pervasiveness of uncertainty also suggest the need in both capability assessment models[5] and spares requirements estimation[6] to take explicit account of more realistic levels of peacetime and wartime uncertainty and also of the support system's ability to cope with some of this uncertainty through widely used management adaptations. This need exists in every stage of the planning, programming, budgeting, and execution system.

THE CLOUT INITIATIVES

The general approach to the uncertainty problem and the set of specific initiatives that have emerged from this work are called CLOUT (Coupling Logistics to Operations to meet Uncertainty and the Threat). The CLOUT initiatives are examples from a taxonomy of more generic strategies for coping with uncertainty.[7] They are intended to enhance the flexibility and responsiveness of the logistics system in the theater, at the Air Logistics Centers, and in command and control systems, thus enhancing the robustness of system performance in the face of uncertainty. Although this report describes the CLOUT initiatives with emphasis on their application to the Tactical Air Forces, our expectation is that this initial set of initiatives will be augmented by other initiatives that extensions to this work will identify. In fact, some of these initiatives and some extensions to them are reflected in the new Logistics Concept of Operations and the Logistics Strategic Plan.[8] Moreover, a study is currently being formulated at RAND that is intended to develop and demon-

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[4]See the discussion in Lippiatt, Thomas F., *Variability in the Budget Forecasts for Depot-Level Component Repair*, RAND, N-2930-P&L, 1991.

[5]A capability assessment model was developed to support the analyses reported here. It is described in Isaacson, Karen E., and Patricia Boren, *Dyna-METRIC Version 5: A Capability Assessment Model Including Constrained Repair and Management Adaptations*, RAND, R-3612-AF, August 1988.

[6]Another RAND project has been established as an outgrowth to this work under the auspices of the Resource Management and System Acquisition Program of Project AIR FORCE to develop improved spares and repair estimation methods that take account of realistic levels of uncertainty and the effects of management adaptations.

[7]See the discussion in Hodges and Pyles, pp. 20–24.

[8]*US Air Force Logistics Strategic Plan*, Department of the Air Force, DCS/Logistics and Engineering (AF/LEYX), Revised October 1990.

strate a multiechelon spares and repair and financial management system for the Air Force that will explore additional means for implementing these initiatives.

Essentially, the CLOUT initiatives generally place less reliance on a richness of spares and take greater advantage of more flexible resources, such as maintenance and transportation. That strategy derives logically from the difficulty and cost of a "buyout" strategy that would attempt to provide ample quantities of spares, for example, to allow the system to cope with the levels of uncertainty in demand that it might face. Though the difficulty of a buyout strategy for wartime may be self-evident, such a strategy is also troublesome for peacetime. Even in peacetime, buyouts are not likely to be economical, and they can be especially problematic in a constrained funding environment. At the theater level, there are significant payoffs to be gained from alternative operating policies for theater distribution systems that take fuller advantage of responsive lateral resupply and lateral repair options. Capability assessments also suggest that closer coupling of the depot repair system to the combat forces has significant payoff in aircraft availability. The thrust of the thinking underlying CLOUT is to rely less on an ampleness of goods and more on management adaptations.[9] That thinking has important implications for system design as well as management. Many characteristics of the current system need to be changed to achieve the kind of relevant, timely, and robust performance needed to cope with unanticipated, urgent demands for resources.

The theater-level CLOUT initiatives are as follows:

- Lateral repair by bases with repair capability to support bases that would otherwise have to send their repairable assets back to the depot for repair.

- Forward stockage, with emphasis on intermediate-level test equipment parts, shop replaceable units (SRUs), and lower-demand parts that do not qualify as War Reserve Materiel (WRM).

- Responsive theater transportation to support lateral resupply, forward stockage, lateral and theater (rearward) repair, retrograde, and distribution of assets coming into the theater.

- Improved operating policies and decision rules in prioritizing the repair of assets and allocating them to bases with the objective

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[9]Hodges and Pyles, p. 23. Hodges describes these two approaches as examples of passive and active strategies, respectively, to cope with uncertainty.

of achieving dynamic aircraft availability goals at each of the bases.

Clearly, several of the CLOUT initiatives are already used in some form by logistics managers in the current system to overcome urgent, unanticipated demands for resources. Cannibalization and lateral supply are examples of adaptive management that can help overcome asset shortages. Logistics managers often resort to these and other adaptations. The distinction between such adaptive behaviors and the CLOUT initiatives is that the CLOUT initiatives are meant to be systemic, implemented with full visibility of the theaterwide or worldwide asset position, and oriented explicitly toward the achievement of specified aircraft availability goals.[10] Thus they cannot always be implemented by local managers. In addition to extending the manager's ability to adapt, CLOUT is intended to facilitate and improve the adaptations that are already available.

There is a need, of course, to consider the vulnerability of transportation and communications systems and assets in wartime. A system built on the assumption of worldwide visibility of the asset position and available transportation must be carefully thought through in terms of its viability in combat. It should be noted, too, that systemic implementation of the kinds of initiatives described here would require policy changes that would make them operationally accepted. For example, when a base receives a redistribution order directing the reallocation of an asset, it would need to respond promptly with the shipment (unless, of course, there was reason to believe that an error had occurred). Similarly, unit commanders would need to subscribe to the concept of mutual base support in a practical sense. It doesn't seem that such an idea is unreasonable. Commanders might have good reason to believe that they might gain as much from such mutual support as they would give up to it.

The "wholesale" and depot-level CLOUT initiatives include the following:

- Responsive, assured intertheater transportation.[11]

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[10]An Air Force reporting system currently in use provides visibility of the worldwide asset position of recoverable items. Called AFRAMS (Air Force Recoverable Asset Management System), it provides data to an AFLC system used by item managers and others for various item management functions.

[11]We use the term "assured" to mean that transportation is always available. It is more of an assumption than a fact because it assumes that higher-priority requirements do not interfere with the transportation of aircraft spare parts. We do not discuss here the management systems or other resources required to "assure" transportation.

- Enhanced flexibility and responsiveness of the depot's repair process to increase the timeliness of repair actions and their relevance to the current needs of the combat force.

- Distribution of serviceable assets that explicitly accounts for mission urgency and the current asset position worldwide.

THE POTENTIAL PAYOFF

Assessments of the CLOUT initiatives suggest the magnitude of the effects of particular uncertainties on the performance of the logistics system and the payoffs that might be achieved through a more relevant, timely, and robust support system. They show that responsive lateral supply and lateral repair improve system performance substantially, and that theater-level priority repair helps the system cope with demand uncertainties even when individual repair facilities are saturated with workload. Responsive depot repair also pays off. It helps mitigate the effects of additional uncertainty in demand for NRTS[12] assets and provides crucial test equipment repair parts to the theater. The CLOUT initiatives also support alternative force beddowns better than the current system and help reduce the disruptive effects of base attacks.

Although particular aspects of logistics system management are emphasized in this report, its underlying thinking applies to other areas of management. For example, responsive depot support depends heavily on assured, responsive transportation and timely handling and processing of assets in transit from the depot to the base and in retrograde shipment. We do not address many of the important issues involved in making these parts of the logistics system more responsive; yet, they are only a few of the many aspects of logistics management that need to be modified in terms of goals, incentive structures, operating policies, management systems, etc., before the total system is genuinely responsive.

PLANNING FOR UNCERTAINTY IN A CHANGING WORLD

Between the time this research was done and the time of this publication, the world has changed dramatically. The scenario that provided the context for this work was a high-intensity conventional conflict between NATO forces and those of the Warsaw Pact. This scenario was based on prescribed national policy. The Uncertainty Project ob-

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[12]Not repairable this station. Defective assets beyond the repair capability of a base, typically returned to an Air Logistics Center for repair.

served that there was likely to be considerable variation associated with many aspects of this scenario—variation not taken into account in forecasting the demand for support. The new environment faced by military planners is quite different in some ways, but quite similar in others. The high-intensity European conflict provided a prescribed scenario for military planners. Many felt that if resources were adequate for the European scenario, they would be adequate for other scenarios which could be expected to absorb a smaller proportion of the force. Given the changes in the world in recent months, the European scenario no longer has the same significance in planning and resource allocation decisionmaking. The Air Force now faces a planning problem in which there is great uncertainty about the range of scenarios it is likely to face and the variation that is likely to exist within each scenario.

This work points out the important fact that, in any scenario, units may face shortages that need to be overcome in very short response times. That is likely to be the case no matter what specific combat scenario evolves. Thus the need for flexible, adaptive management and mechanisms for supporting it persists for military planners. In general, management adaptations like the CLOUT initiatives help the logistics system achieve needed levels of responsiveness, enhancing its robustness not only for a European scenario, but in the face of uncertainty about what scenario will evolve, what mix of weapons will be needed, when, where, etc. Specific initiatives, however, may not have the magnitude of benefit in particular scenarios that they might have had in a high-intensity NATO scenario. Intratheater lateral supply, for example, depends on having more than one base with a specific weapon system within reasonable proximity in a theater.

Management adaptations yet to be defined and evaluated may turn out to be important in any particular future scenario. While such initiatives obviously need to be understood in terms of their applications to specific situations, their implications for combat support are still important, despite the fact that the traditional threat seems to have changed. They may become even more important, given our greater uncertainty about the kinds of future threats we will face. At the time of this writing, Operation Desert Shield/Storm has ended, but final evaluations have not been completed. However, that experience has tended to confirm the principal assumptions and outcomes of this study. Prediction is indeed hazardous; adaptations are extremely important; and quick response is what the forces in the field expect. In any event, this report discusses the NATO scenario and not regional contingencies. We trust that this emphasis will not interfere with the communication of the basic CLOUT views.

The implications of this approach for logistics management, logistics policy analysis, and the design of logistics management systems are fundamentally important. The implications of uncertainty in particular applications are sometimes both difficult and unfamiliar for many persons. To illustrate some of the issues involved and to suggest that there are feasible approaches for dealing with them, in Sec. 5 we discuss two examples of applications, one involving the prioritization of component repair and the other the estimation of spares and repair requirements.

IMPLICATIONS

Perhaps the most important central message of this work is the need to take more explicit account of uncertainty, particularly state-of-the-world uncertainty, in formulating policies and designing systems, and to take explicit steps to ensure that the performance of those policies and systems is robust in the face of those uncertainties. This doesn't mean that the uncertainties actually faced will indeed be matched by the existing robustness of the system. It does suggest, however, that it is more realistic to emphasize robustness than to behave unrealistically, as if demands were known, designing systems that are optimized to meet those questionable demands.

The CLOUT initiatives are examples of management adaptations that enhance the performance of the logistics system in peacetime and wartime. As we have shown, they help mitigate the effects of uncertainties. To the extent that we ignore statistical and, especially, state-of-the-world uncertainties in logistics planning, particularly for wartime, we are vulnerable to events unfolding in ways that defeat specific solutions. To the extent that we take explicit and realistic account in planning of our uncertainties and the effects of management adaptations in overcoming them, we will be better able to develop solutions whose performance is robust in the face of uncertain futures. This is the fundamental message of this work. It is a message that applies to broad categories of management decisionmaking and policy analysis. It is an important message for Air Force logisticians and for those involved in logistics management system design.

ACKNOWLEDGMENTS

It is difficult to imagine how this work could have been undertaken without the special relationship that exists between the Air Force and RAND under Project AIR FORCE. For that relationship we are grateful. Within that context many individuals in the Air Force and at RAND deserve credit for the work discussed in this report. Their names and contributions would fill several pages. If we were to single out one senior person in the Air Force and another at RAND who participated in and supported this work in extraordinary ways, we would mention Major General Edward R. Bracken, USAF, and Michael D. Rich.

CONTENTS

FIGURES

TABLE

GLOSSARY

AAM	Aircraft Availability Model. A computational algorithm developed by the Logistics Management Institute to allocate stock levels of recoverable assets in a way that approximately maximizes aircraft availability subject to a budget constraint. It is used by AFLC to compute procurement requirements for recoverable aircraft spares.
AFLC	Air Force Logistics Command.
AFRAMS	Air Force Recoverable Asset Management System. A system of asset reporting that provides central visibility of recoverable assets worldwide.
AIS	Avionics intermediate shop. The maintenance shop that repairs avionics LRUs. Shops with this name are located at bases as well as the depot.
BCS	Bench check serviceable. The result of fault diagnosis that fails to confirm a defect.
BLSS	Base level self-sufficiency stock. Spares that are authorized for units that are expected to fight in place. In the context of this research, BLSS is authorized for main operating bases.
C^3	Command, control, and communications.
COB	Collocated operating base. Allied bases that are expected to host the deployment of USAF units in wartime.
CONUS	Continental United States.
CRAF	Civil Reserve Airlift Fleet. The commercial aircraft that are planned to be used to enhance our military airlift capacity in wartime.
CSIS	Central secondary item stratification.

D028	AFLC's central system for allocating stock levels for recoverable spares to the depot and bases.
D041	AFLC's system for computing requirements for recoverable spares and depot-level repair.
D056	AFLC's system for collection, processing, and analysis of worldwide maintenance data.
D143	AFLC's system that provides central visibility of the worldwide asset position for recoverable assets. It operates with data from the AFRAMS.
DRIVE	Distribution and Repair In Variable Environments. A prototype algorithm for prioritizing the repair of recoverable assets at the depot and allocating the serviceable assets that emerge from repair to locations to maximize the probability of achieving specified aircraft availability goals.
Dyna-METRIC	Dynamic Multi-Echelon Technique for Recoverable Item Control. RAND has developed a series of capability assessment models to support policy analytic studies of the logistics system. Dyna-METRIC Version 4, an analytic model, is incorporated in AFLC's Weapon System Management Information System (WSMIS). Version 5, a simulation model, was used in this research. Version 6, an advanced, hybrid analytic-simulation model, the latest version of the Dyna-METRIC series, extends Version 5 to incorporate the indenture relationships among LRUs and SRUs, and adds more explicit representation of management adaptations.
Dyna-SCORE	Dynamic Simulation of COnstrained REpair. A discrete-event, Monte Carlo simulation model of repair shops similar in repair process to the avionics integrated shop. Dyna-SCORE was developed to explore the payoffs of certain management adaptations in repair activities.

EDS	European Distribution System. The intratheater airlift system of the United States Air Forces, Europe.
Force beddown	The posture of the combat force in terms of numbers of aircraft of each type at each location. The force beddown could also be specified by aircraft serial number.
I-level	Intermediate level. The term used to describe the maintenance activities that repair assets for return to aircraft or to base stocks; the level of maintenance between the organizational and depot levels.
LRU	Line replaceable unit. Components that are removed from aircraft when a discrepancy is suspected. In the indentured relationships among component parts of an aircraft, for example, they are typically thought of as component parts of subsystems.
MICAP	Mission capability. A term used to describe a condition such that an aircraft is not mission capable for lack of a component part. The requisition in the supply system for that component part is called a MICAP requisition.
MOB	Main operating base. A base that has the infrastructure associated with peacetime support of an Air Force unit, typically a wing, that is expected to fight in place in the event of a war.
Monte Carlo trial	Replication of an experiment to estimate experimental error in which outcomes are determined purely by chance.
NATO	North Atlantic Treaty Organization.
NFMC	Not fully mission capable. The status of an aircraft that is flyable, but whose capability to perform its assigned mission is in some sense degraded, constrained, or inhibited.
NRTS	Not repairable this station. The status of a recoverable asset that cannot be repaired at intermediate level and must be returned to the depot for repair.

PDS	Pacific Distribution System. The proposed intratheater airlift system of the Pacific Air Forces.
POS	Primary operating stock (formerly peacetime operating stock). Spare parts authorized to bases to support peacetime operations but which may also be used in wartime.
PPBES	Planning, programming, budgeting, and execution system.
RR WRSK	Remove and replace war reserve spares kit. A WRSK computed using the assumption that no intermediate repair capability exists.
RRR WRSK	Remove, repair, and replace war reserve spares kit. A WRSK computed using the assumption that intermediate repair capability will be available in wartime.
SRU	Shop replaceable unit. A subcomponent of an LRU which is typically removed and replaced during intermediate-level repair.
UK	United Kingdom.
VTMR	Variance-to-mean ratio. The unbiased estimator of the variance divided by the mean of a process.
WMP	War Mobilization Plan.
WRSK	War reserve spares kit. A set of spare parts that is authorized to a unit to help support its combat operations during the early days of wartime.

1. INTRODUCTION

Air Force logistics planning for wartime is based on several troublesome assumptions. The assumption that underlies the Air Force's computations of war reserve spares requirements implies a level of variability in demands substantially less than the level actually observed in peacetime. Moreover, the uncertainty in peacetime resource demands will be compounded in wartime by system disruptions, resource losses, and the inevitable surprises of combat. Another troublesome assumption is that no spares need to be procured to provide for the pipeline of components removed from aircraft in the belief that they are defective but subsequently diagnosed as serviceable. Such assumptions, coupled with the levels of uncertainty that pervade the wartime environment, tend to induce an unwarranted level of optimism in logistics planning.

This research was undertaken to understand the implications of these uncertainties better and to identify and evaluate initiatives to overcome them. This "Uncertainty Project" addressed these issues, especially as they apply to the Tactical Air Forces. Its objectives were to:

- Improve the Air Force's understanding of the magnitude and extent of the variability in peacetime demands for logistics resources.

- Develop and evaluate alternative methods for increasing the flexibility, robustness, and responsiveness of the logistics system at both the base/theater and depot levels to increase readiness and sustainability in the face of the uncertainty in peacetime demand that would undoubtedly increase in wartime.

- Define and evaluate the logistics command, control, and communications (log C^3) systems and other mechanisms by which the infrastructure should be tasked to support the "real-time" needs of the combat forces.

The set of initiatives that has emerged from this work is called CLOUT (Coupling Logistics to Operations to meet Uncertainty and the Threat). The CLOUT initiatives are designed to enhance the flexibility, robustness, and responsiveness of the logistics system in the theater, at the Air Logistics Centers, and in command and control systems.

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TASKS

The project consisted of six major tasks:

1. Assess the magnitude and pervasiveness of variability in demand for logistics resources and its impact on logistics readiness and sustainability measures.

2. Identify and evaluate responsive base/theater alternatives, logistics support structures and strategies, and improved intratheater transportation.

3. Identify and evaluate responsive depot alternatives. These alternatives include flexible, adaptive repair and the development of scheduling algorithms to ensure that spare parts and other resources are repaired and distributed to meet the immediate needs of combat forces.

4. Define and evaluate logistics command and control systems at Air Force Logistics Command (AFLC) and in the theater to assess the current needs of the forces, and translate those needs into action by providing directions to various repair and distribution elements of the logistics infrastructure.

5. Develop models for use in evaluating the repair capacity of selected base-level or depot-level shops.

6. Develop an approach to estimating spares and repair requirements in light of demand uncertainties and management adaptations.

PROJECT RESULTS AND REPORT ORGANIZATION

The Air Force has embraced the ideas discussed in this report and has included them in a new Logistics Concept of Operations, the implementation of which is now being thought through by the Air Staff and the Major Commands. It emphasizes the "fog and friction" of war, and it appeals to the use of CLOUT-like management adaptations to help the logistics system cope with the uncertainties of combat scenarios. The thinking underlying the ideas discussed in this report has implications for the other Military Departments as well.

The results of the first task were published and are available in a previous RAND report; they showed unanticipated levels of variability in the peacetime demands for aircraft spare parts.[1] Some of those findings and their implications are discussed in Sec. 2 of this report.

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[1]Crawford, Gordon B., *Variability in the Demands for Aircraft Spare Parts: Its Magnitude and Implications*, RAND, R-3318-AF, January 1988.

Section 3 discusses an alternative approach to logistics system design, intended to make its performance more robust in the face of uncertainties. The results of the evaluations of some of the CLOUT initiatives are discussed in Sec. 4. The capability assessment model developed and used for these evaluations is also described in a previous RAND report.[2] In Sec. 5, we describe very briefly the problem of prioritizing depot-level component repair and the research currently under way in estimating spares and repair requirements as practical examples of the kind of thinking that underlies the initiatives discussed in this report. We offer some concluding remarks and recommendations in Sec. 6.

Our work in this project in developing and demonstrating a mechanism to prioritize depot component repair to make the depot more responsive to the current needs of the combat force is described in two companion reports.[3] RAND's research in logistics command and control systems was undertaken in a separate project, and was also described in a separate report.[4] The model used in this work to explore the policy alternatives affecting depot maintenance shops, called Dyna-SCORE (Dynamic Simulation of Constrained Repair), was described in an earlier report.[5] Finally, the research to incorporate explicit consideration of uncertainty and management adaptations in spares and repair requirements estimation is still ongoing in a separate, follow-on project, and is planned for publication in 1992.

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[2]Isaacson, Karen E., and Patricia Boren, *Dyna-METRIC Version 5: A Capability Assessment Model Including Constrained Repair and Management Adaptations*, RAND, R-3612-AF, August 1988.

[3]Abell, John B., et al., *DRIVE (Distribution and Repair In Variable Environments): Enhancing the Responsiveness of Depot Repair*, RAND, R-3888-AF (forthcoming) and Miller, Louis W., and John B. Abell, *DRIVE (Distribution and Repair In Variable Environments): Design and Operation of the Ogden Prototype*, RAND, R-4158-AF (forthcoming).

[4]Gustafson, H. Wayne, *Combat Support Command, Control, and Communications (CSC³): Robust Methods to Mitigate Communications Disruptions*, RAND, R-3942-AF, 1991.

[5]Tsai, Christopher L., *Dyna-SCORE: Dynamic Simulation of Constrained Repair*, RAND, R-3637-AF, July 1989.

2. UNCERTAINTY IN RESOURCE DEMANDS

In peacetime as well as war, demands for support are impossible to predict. Even if we accept the flying programs in formal planning scenarios and assume no deviation, we soon discover that we cannot reliably anticipate demand in the real world. The problems in predicting spare part demands in peacetime have been observed over a long period. An early major report on this unpredictability was written at RAND in 1957 by Brown.[1] Over the years, similar studies have been published.[2] More recently, Crawford quantified the magnitude and pervasiveness of variability, and thus unpredictability, in the demands for aircraft recoverable spare parts, and pointed out that such variability extends to the numbers of assets in resupply pipelines.[3] Crawford's work was the latest in a long history of RAND research into the problem of forecasting the demand for aircraft spare parts that began in the 1950s and is still being carried on. The lesson emerging from the current work is that although improvements in forecasting may be achievable, parts demand processes have such large inherent variability that they tend to swamp out such improvements; therefore, a logistics system with enhanced flexibility and responsiveness seems to be the best approach to coping with uncertainties in resource demands. Although this work focuses on avionics line replaceable units (LRUs), it is safe to assume that the same logic applies to other resources.

VARIATION IN SPARE PARTS DEMAND

Figure 2.1 illustrates the kind of variability that we sometimes observe in peacetime spare parts demands. For each of three bases, the graph shows demand rates[4] over several years for the F100 engine unified fuel control. The striking message is the high variation of demand from quarter to quarter and from base to base. This variation is so great that, no matter where one imagines himself in time, it

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[1]Brown, Bernice B., *Characteristics of Demand for Aircraft Space Parts*, RAND, R-292, July 1956.

[2]See Bibliography.

[3]Crawford, op. cit.

[4]Removals for apparent cause per 1000 flying hours.
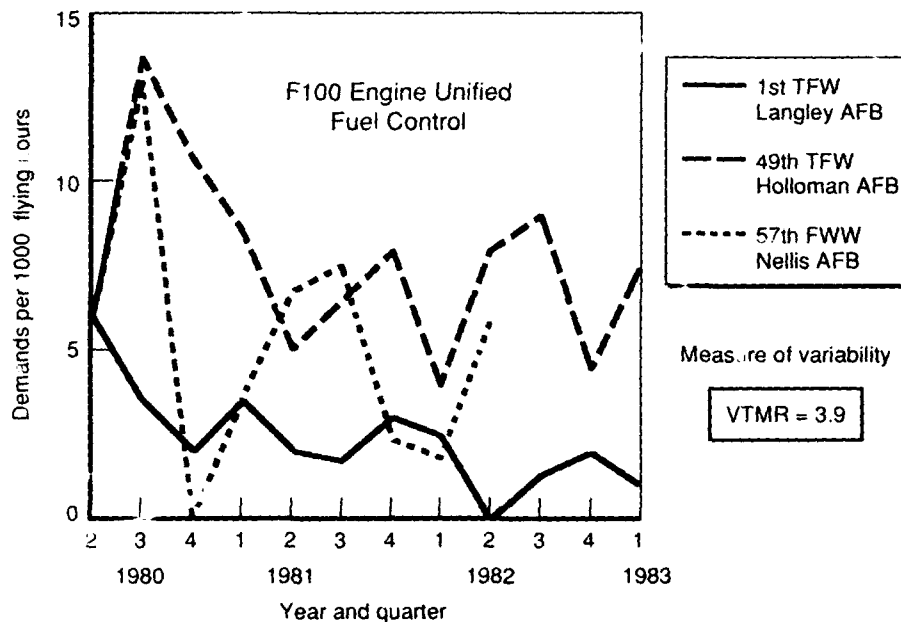
Fig. 2.1—Variability in Demand Rates for F100 Engine
Unified Fuel Control

is very difficult to predict the next quarter's demand. This variation can be expressed as a single number: the variance-to-mean ratio (VTMR).[5] For this example, the VTMR is nearly four.

Figure 2.2 tells a similar story for another component: the F-15 converter programmer. Again we see variation both within a base and across bases, but in this case the variability is even larger; the VTMR is nine.

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[5]The variance-to-mean ratio is computed using the unbiased estimator of the variance divided by the mean demand rate. It has the form $[(n/(n-1)][E(X^2) - E^2(x)]/E(X)$, where X represents the observed demands and n denotes the number of individual observations. The period of observation as well as the partitioning of the observed data into intervals affects the numerical value of the estimator. In this example, we used quarterly observations as used by AFLC in its estimations of demand variability for purposes of computing requirements, not necessarily the "best" partitioning in any statistical estimating sense, but one with which logisticians are most familiar. Regardless of the data partitioning, the estimates shown here seem large when contrasted with those that would result from a Poisson demand process which is assumed in the Air Force's computations of its war reserve spares requirements.
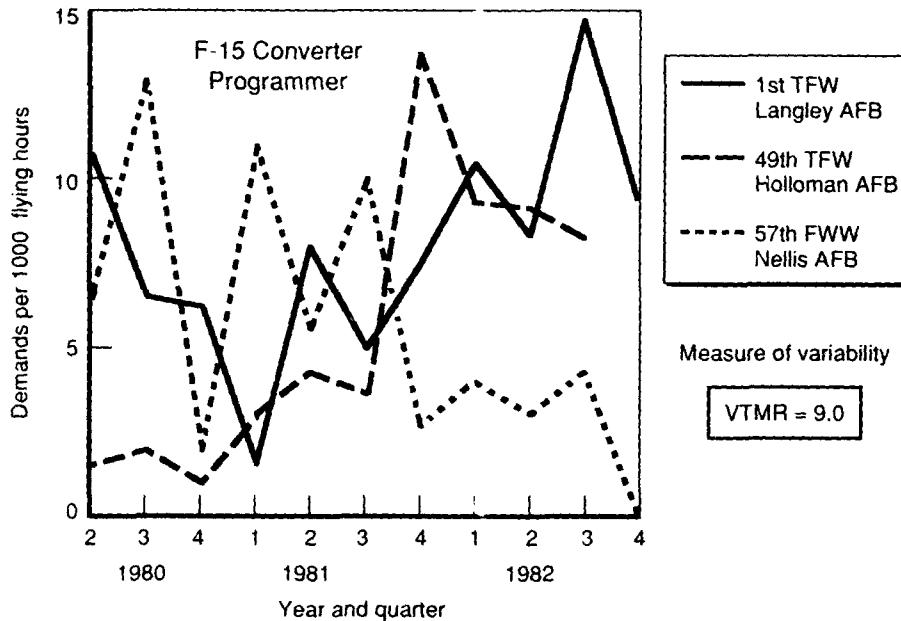
**Fig. 2.2—Variability in Demand Rates for F-15
Converter Programmer**

Faced with these kinds of observations, one may conclude that this variability is caused by some special phenomenon. In an attempt to formulate some reasonable hypotheses about the factors causing unanticip ited and variable demand for the same component, we int rviewed a number of maintenance personnel who have experienced these changing demand levels in the field. We found as many different responses as there were respondents; explanations included variitions in: climate, scheduled maintenance practices, operational use if aircraft, component wear and tear characteristics, crews' malfuncion reporting, new and modified components used, maintenance kills, and types of mission flown. Even if these explanations are corect, they are oftentimes unknowable in advance; moreover, they are) varied that no suitable hypothesis can be drawn. We concluded iat whatever is causing the variation cannot be predicted.

his large peacetime demand uncertainty is unlikely to diminish durg war. Even in a benign wartime environment—i.e., one where 'ing hours increase but no losses occur—it seems reasonable to beve that demand rates will differ from those seen in peacetime. In acetime, one might even argue that, over time, inroads in pre-

dictability will occur, at least for those observations made for repeated conditions. In the wartime case, however, such inroads are less likely for many reasons. The sortie conditions studied and understood in peacetime may not occur in wartime, for example, and the actual conditions that might be faced in wartime may bring some unanticipated outcomes. In a threatening and demanding wartime environment, aircrew and maintenance responses to equipment degradation are likely to be different from their responses in peacetime. Moreover, the specific actions that might be taken by the enemy, and thus the resulting demands for resources, are likely to be unknowable. To take just one example, Rich et al. have pointed out that U.S. Air Forces have almost always enjoyed air superiority over their own bases and facilities.[6] That superiority, although enjoyed in the recent Gulf War, is no longer assured. Contingencies could evolve in which demand could be dramatically intensified by enemy attacks against airbases and other parts of the support infrastructure that disrupt the combat support system and destroy critical resources. The Air Force continues to pursue initiatives that are expected to inhibit and reduce the impact of enemy attacks against its bases. Mitigating the effects of much of the damage suffered in such attacks might appropriately be managed by logistics. Thus, in peacetime and benign wartime environments—to say nothing of hostile wartime conditions—demands can be expected to arise in unanticipated ways.

ASSUMPTIONS OF PREDICTABILITY

But even though demand is unpredictable, formal support systems tend to *act as if* that weren't true. Predictability and stability are the premises on which these systems were developed. In each stage of the Planning, Programming, Budgeting, and Execution System (PPBES), formal resourcing mechanisms typically do not make realistic assumptions about uncertainty. The decisionmaking processes underlying the allocation of logistics resources implicitly assume stable, predictable, benign environments.

These assumptions are especially clear, and especially dangerous, in planning for war. For example, the models used by the Air Force for defining a War Reserve Spares Kit (WRSK) assume a VTMR of one.[7]

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[6]Rich, Michael, William Stanley, and Susan Anderson, *Improving U.S. Air Force Readiness and Sustainability*, RAND, R-3113/1-AF, April 1984.

[7]The use of a VTMR of 1.0 is associated witn the assumption that demand follows a Poisson distribution. The Poisson assumption underlies the Air Force's computation of its WRSK requirements. Other probability distributions describing parts demands are

Yet we have just observed actual VTMRs for certain components of four and nine—in peacetime. What does this variation imply for a squadron's performance? Figure 2.3 shows how one measure, the percent of non-fully-mission-capable aircraft (NFMC) during the first 30 days of a postulated NATO wartime scenario, is affected by several different VTMRs when no special action is taken to mitigate the effect of variation. We used a RAND model called Dyna-METRIC to do this assessment.[8]

A VTMR of 1.0 results in about 25 percent non-fully-mission-capable aircraft after 30 days. (This outcome emulates the one assumed in defining the WRSK.) If the actual VTMR is 2.0, that percentage rises to about 40, and so on for higher VTMRs. It is not likely that every component in the WRSK will have a VTMR of 2.0 or more, but neither is it necessary for this to happen before we need to worry about seriously degraded squadron performance. Even if only the critical
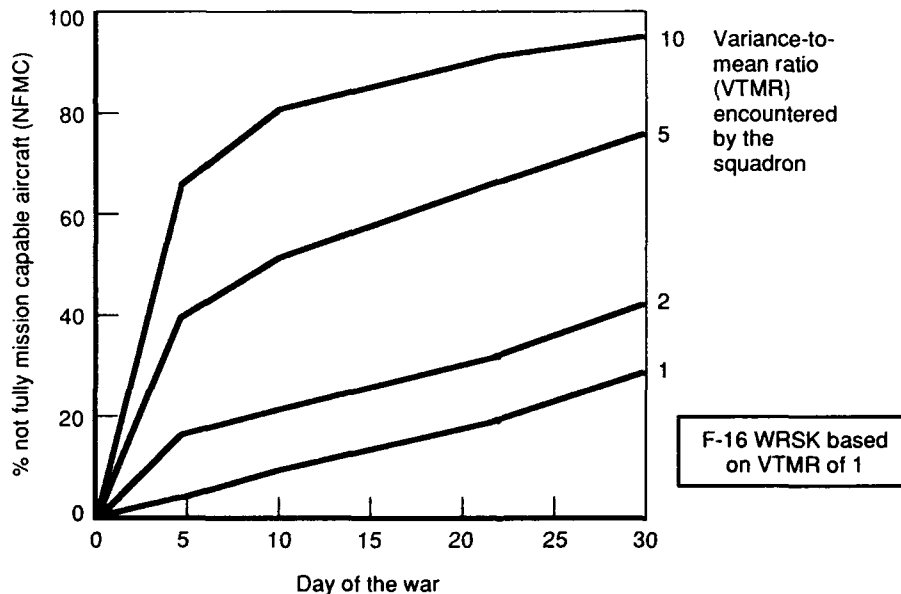
Fig. 2.3—How Variability Affects a Squadron's Wartime Capability

also used by the Air Force in spares requirements computations, but they, too, are members of the Poisson family because they increase the tractability of the problem.

[8]Isaacson, Karen E., et al., *Dyna-METRIC Version 4: Modeling Worldwide Logistics Support of Aircraft Components*, RAND, R-3389-AF, May 1988.

(driving) components have a VTMR larger than one, capability might be degraded. And, clearly, if the real-world VTMR is four, then the WRSK will provide a very different performance from what we had anticipated, even in a benign environment. Of course, special actions by the combat unit could moderate this variability, if they are available and if they are used. Although such management adaptations are common, formal resourcing mechanisms typically ignore them, just as they often ignore uncertainty.

Clearly, the range of variation in real-world demand, even under benign wartime circumstances, presents a problem. One response might be to buy "sufficient" resources to mitigate the effects of unpredictability with inventory. And, indeed, in those few cases where current formal systems address uncertainty at all, that tends to be the approach. Unfortunately, as Fig. 2.4 shows, investing more money may not solve the problem. Even if we were willing to more than double our WRSK investment to accommodate the actual VTMRs, we still might not buy the correct mix of spares because the VTMRs are not stable. As a result, as Fig. 2.4 suggests, for the converter programmer, "buying out" could still result in a shortage of components in the face of a rising VTMR; for the unified fuel control, many parts might go unused in the face of a declining VTMR. While the time periods used in this illustration are relatively short compared to procurement lead times for aircraft spare parts, they do serve to suggest the nature of the problem: instability in observed VTMRs.

	VTMRs of worldwide quarterly demands per 100 flying hours	
	July 1980–June 1981	July 1981–Sept 1982
F-15 Converter Programmer	5.03	10.02
F100 Unified Fuel Control	4.70	2.77

Fig. 2.4—Why Buying Out Is Not the Answer

Moreover, the "buyout" strategy—even if practical for peacetime—does not address the unpredictability of the wartime environment. We do not know how wartime demands will differ from peacetime experience. Conceivably, the adversary could induce the need for unplanned, unanticipated mixes of missions or force beddown changes; damage the support infrastructure; disrupt support systems; or destroy resources. These possibilities make the resourcing problem extraordinarily difficult for the conventional models used in formal systems.

Formal systems deal with the difficulty these risks present by ignoring them. Air Force planning for wartime is based on the use of "planning scenarios." For example, the computation of expected demands for such resources as spare parts, repair, and transportation uses the War Mobilization Plan's (WMP) specified flying programs. Many resources are allocated by using peacetime flying history, merely scaling up peacetime observations (i.e., mix of components to be repaired, repair hours) to reflect the difference between peacetime and planned wartime flying hours. But deviations from these scenarios are inevitable. Yet, typically, capability assessment models are not used to examine the implications of such deviations to warfighting capability. And no attempt is made to predict the demand created by a less-than-benign wartime environment, or to assess how support systems will respond.

For some contingencies, such assumptions of predictability are not prudent; for a high-intensity conflict, such as the NATO scenario implied, they are inappropriately optimistic. Given current resourcing techniques and what the wartime environment might turn out to be, it is virtually certain that some resource constraints will develop at unit level.

This is not simply a problem of prediction. It seems reasonable to assume that wartime will not turn out to be merely a scaled-up peacetime operation. But beyond that, assumptions become simply guesses. We cannot realistically anticipate the demands generated by actual wartime flying programs, much less those created by enemy attacks on infrastructure. In a very real sense, all we can say is that the demands of war are likely to be uncertain and largely unpredictable. Thus, even if we made progress in predicting peacetime demands, the wartime uncertainty would remain. It is likely that some undesirable level of uncertainty will prevail for peacetime, as well. Yet the formal resourcing system consistently assumes the opposite.

THE CURRENT SYSTEM

To understand how thoroughly current planning depends on pre-
dictable demands, consider the existing support systems. The left
portion of Fig. 2.5 provides a schematic of airbases in the theater.
The *main operating bases* (MOBs) have primary operating stock
(POS) and an increment of stock to take care of the increased flying in
wartime called *base level self-sufficiency stocks* (BLSS). The MOBs
have full intermediate-level repair capabilities. Some of the repair
facilities are hardened. However, the *collocated operating bases*
(COBs) may have some weapon systems—for example, the F-16—that
are deployed with only the WRSK, and others—for example, the F-
15—that have a WRSK and limited intermediate-level repair capa-
bility, but no hardening. However, in the longer run, hardening of
some of the repair facilities was planned in the NATO scenario.

Since we intend to provide resources to these organizations to be self-
sufficient for the first 30 days of war, there is an implicit assumption
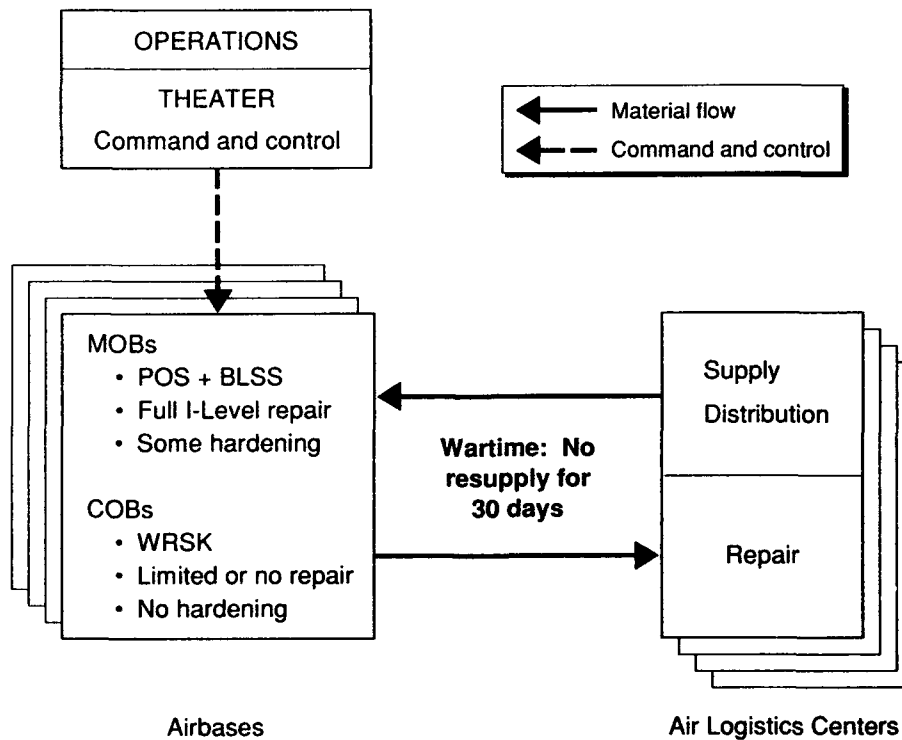

Fig. 2.5—The Current System

that there will be no resupply from the depot during that time. There may, in fact, be some limited resupply. However, the self-sufficiency orientation may, in fact, detract from the system's concern with developing effective resupply and lateral supply systems. Figure 2.6 adds to Fig. 2.5 the uncertainties that may cause the resources provided to be insufficient to meet the needs of the combat forces. The arrow on the left focuses on the uncertainties that the theater might face. As indicated, demands might occur on the flight line that are unanticipated even in "benign" environments. These unanticipated demands may result from the dynamic flying programmed by the Command and Control System. Moreover, as the peacetime data in Figs. 2.1 and 2.2 demonstrated above, unanticipated demands may result in ways that underscore the fact that we simply do not understand the demand-generation process. Furthermore, in the kind of high-intensity war anticipated in the NATO environment, for example, many attacks may cause resource losses or system disruption. It may be that as a result of these attacks, the numbers of surviving personnel, spares, repair resources, and the like within bases will be imbalanced so that the sortie potential of the surviving aircraft will be seriously impaired. Where repair facilities and aircraft shelters are hardened, the extent of this imbalance in surviving resources is likely to be reduced. In anticipation of an attack, elements of the combat forces may need to disperse aircraft and other resources temporarily. After an attack, aircraft may be pinned in or pinned out so that combat operations cannot proceed as planned.

Such eventualities are largely ignored in resourcing combat organizations for wartime. Despite the fact that these kinds of eventualities could dominate the combat scenario, units have been resourced as if demands were predictable. Furthermore, despite critical shortages that might develop, plans for using the depots in such circumstances remain, at best, in doubt.

In effect, the prevailing view is that resources are provided for 30 days, and hence no resupply needs to take place for this period of time. This view is reinforced by instructions to organizations deploying without maintenance to delay the repair of removed components until maintenance arrives at the unit during the last week of the 30-day period. Of course, when the need arises, it is likely that resupply will indeed take place. However, the uncertainty orientation would suggest that the need for resupply is inevitable and that aggressive

OPERATIONS

THEATER

Command and control

——— Material flow

——— Command and control

···· Effects of unpredictable factor

Uncertainty

Unplanned demands
• Dynamic flying programs

Uncertain threat
• Airbase attack
• Need to disperse

MOBs
• POS + BLSS
• Full I-Level repair
• Some hardening

COBs
• WRSK
• Limited or no repair
• No hardening

Wartime:
No
resupply
for
30 days

Supply

Distribution

Repair

Peacetime

Distribution priority: Oldest requisition first

• Not timely or relevant
  – Quarterly contract
  – Uses old data
• MICAPs have priority

Airbases

Air Logistics Centers

Fig. 2.6—The Current System with Uncertainties

management systems for retrograde[9] and resupply should be planned for and should be in place.

The right side of Fig. 2.6 presents the depot side of the operation in peacetime. The peacetime system is described because the plans for wartime operation are unclear. In wartime, overrides to the standard system probably will be required. Yet, these overrides are not made explicit. Here the problems stem from the unpredictability of demand and the assumption of a stable, steady-state system. We examined unpredictability in Figs. 2.1 through 2.4; we now turn our attention to the assumption of a stable, steady-state system.

The problem of shortages is not limited to unanticipated demands. More often than not, logistics system managers recognize that short-

[9]The evacuation of repairable assets from the theater of operations to Air Logistics Centers in the continental United States (CONUS).

ages *do* and *will* exist and that management systems need to be designed to *respond to* these shortages. Thus there has been a continuing interest in providing differential support among units, missions, theaters, etc. The importance of setting goals for combat units so that resource allocations can be made to "make the best of" available resources in the face of differences in unit or mission priorities is receiving increasing attention.

Within existing priority groupings, the current system distributes assets in the order in which they were requisitioned. The oldest requisition is the first filled. This scheme may be appropriate in an operation where demand is both predictable and stable; in the Air Force recoverable spares management system, it is neither. As a result, what is distributed to a base may bear little relationship to need.

On the repair side, the system is similarly hampered by the misguided assumption that demand is predictable. Repair contracts are established using old asset position and demand data to predict what the demand will be for the next several quarters. If demand rises above a quarter's prediction, the tendency is to defer that demand until the next quarter. The hazard is a repair system that may be neither sufficiently timely nor sufficiently relevant. Overrides to the system will obviously occur, and those overrides will give emphasis to emerging needs rather than predicted needs. Without specific planning and detailing of a wartime system and without a "fine-tuning" of near-real-time system needs during peacetime operations, it's less likely that the depot will be as timely and as relevant as it needs to be.

The exception to this unhappy situation is a MICAP.[10] When an airplane is down for lack of a part, that part is handled with dispatch in the depot repair system. It could perhaps be handled with more dispatch, but at least the criterion is appropriate: the *airplane*, rather than the *part*. It is this portion of the system that could make the system more timely and relevant in wartime. This is likely to be especially so *if* repairable assets are transported to the depot promptly. What is obviously required is more explicit planning and implementation procedures regarding extraordinary depot responsiveness in wartime. This need was reinforced by Operation Desert Shield/Storm, during which *ad hoc* procedures were often invented to cope with particular urgent shortages.

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[10]A parts shortage affecting MIssion CAPability.

3. AN ALTERNATIVE APPROACH

Although formal support systems underestimate the variation in peacetime demand, the logistics system itself continues to function, meeting unanticipated demands much of the time. Informal management adaptations, ignored by the formal resourcing system, often solve the problem. These actions provide clues to the institutional arrangements and formal management adaptations the Air Force should use to extend management's ability to address uncertainty—especially the greater amounts of uncertainty that might exist in wartime. Basically, they suggest a very responsive and adaptive support system—one that that will react quickly and positively to meet unanticipated demands. This report represents an attempt to devise such changes, integrating Logistics and Operations so that the logistics system can do a better job of meeting resource demands, despite their unpredictability.

FOCUS OF THE ANALYSIS

At this stage, the initiatives are narrowly focused on a logistics operations or *execution* system. Figure 3.1 shows the scope of functions studied to date. Although the issues we have discussed may be relevant to many other facets of logistics, our suggestions currently focus on one critical resource: aircraft recoverable spare parts. They encompass the processes of supply and repair, both at the depot and at the base; flight line removal and replacement; and transportation and distribution.

The functions displayed in Fig. 3.1 are parts of the execution stage of the PPBES (Planning, Programming, Budgeting and Execution System). Within this stage, repair, workloading, and distribution (location) decisions are emphasized. Other functions in the stage, such as procurement, are not discussed. Although the current analysis emphasizes this portion of the PPBES, the ingredients of a preferred execution system need to be reflected in the other stages of the PPBES. Section 4 provides examples. For the present context, suffice it to say that functions within a stage and the four stages of the PPBES must be integrated and act in concert with one another.

15

Airbases   **Air Logistics Centers**
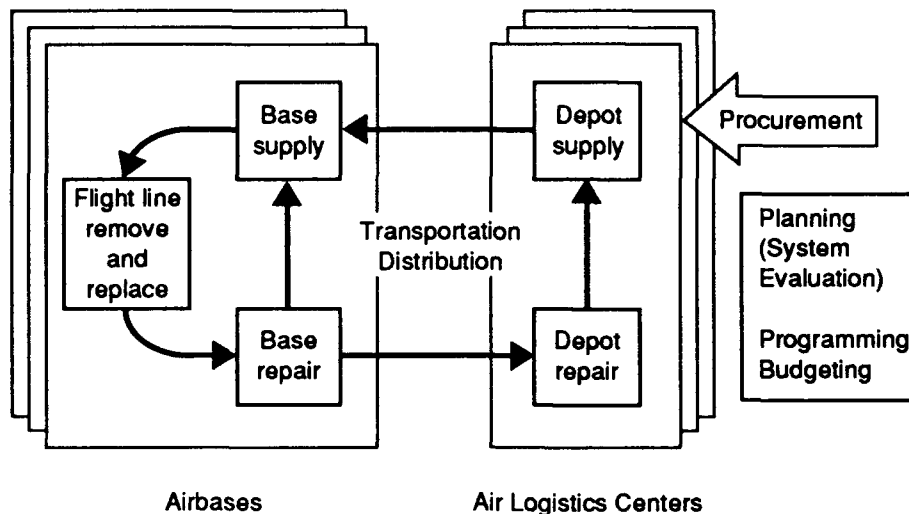
Fig. 3.1—Scope of the Analysis

KEY PRINCIPLES

To make the execution stage in the PPBES less vulnerable to the large errors in decisionmaking that might result from uncertainty, we suggest reducing, where possible, dependence on long-term prediction of demands.[1] The first principle behind this strategy is that logistics operations be based on demands as they become known in real time and as they are predicted more reliably over *very short horizons*. Although even these predictions will often be wrong, especially in wartime, hedging strategies that make and revisit allocations over such short periods are likely to be useful.

Misallocations are inevitable, of course, but one powerful tool for dealing with them is to reduce response times. When unanticipated demands occur, a support system with very short response times can mitigate the effects of such misallocations through lateral supply, very timely depot replenishment, or other management actions. Shorter response times also reduce pipelines, thereby reducing safety stock requirements and total spares investment costs.

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[1]Clearly, this is not always possible, especially in decisionmaking about capital investments, repair capacity, contract repair, and similar decision contexts in which one is constrained to longer lead times.

The second principle of this approach is that Logistics must be linked very closely with Operations. System performance goals provide an important part of that link. It is suggested that the role of the Logistics community is to provide Operations with the necessary number of weapon systems appropriately configured to meet mission needs *as judged by Operations*. Of course, support is inherently a collaborative process. There are often various ways to meet a given operational need, and the differences may be important to Logistics. Also, because of "inevitable" resource constraints, appropriate compromises may need to be worked out by Operations and Logistics personnel. But if analysis of the support system at this level is to be feasible, the judgments by Operations cannot be at issue.

To make the proper decisions that will provide each unit with the necessary resources, Logistics needs appropriate goal measures. To ensure that these measures reflect operational needs tempered by the feasibility of attainment, they should be set by Operations in concert with Logistics. Goals related to weapon systems performance, unlike those that focus on components or commodities, closely reflect operational and mission urgencies. They also promote a common understanding by Operations and Logistics personnel. The system performance strategy, then, is this: *Decisions reached with current asset status information should use weapon system needs as the objective function.* In this report, aircraft availability is used as the goal measure.

With its focus on very short planning horizons, the system must be especially sensitive to rapidly changing needs. Especially in high-intensity warfare, it seems vital to give those directing wartime operations the flexibility to employ units in accordance with dynamic operational urgencies. Operations may alter its assessment of the relative mission importance of some units, for example. As a result, aircraft availability goals might be changed. New allocation and reallocation of assets will be required. Even if unit availability goals stay relatively constant, allocation/reallocation of unit resources may often be needed to help Operations achieve its goals. Repair might be constrained, for example, by inadequate capacity, shortages of bits and pieces, or damage from enemy attacks.

When resources are constrained, the logistics system must use whatever resources are available to satisfy the most critical needs of the combat forces. This may mean the *reallocation* of resources *across* units as well as the *allocation* of incoming resources from the Continental United States (CONUS) or elsewhere. In addition to maintaining a focus on units or bases, we need to consider the totality

of resources, unit, theater, CONUS, and worldwide, and to determine how those resources can be allocated or reallocated to provide support where it is most needed. This suggests the need for an effective priority system, one that discriminates among alternatives in a way consistent with operational urgencies. But the common approach, merely saying that one weapon system is more important than another, provides little help. Typically, priorities are useful only where there is a means for indicating the relative importance of weapon systems by the quantitative use of goal statements. Thus, weapon availability goals by unit potentially provide a more operationally useful means for allocating resources. Aircraft availability goals specified by unit will permit statements of differential needs across bases (even within the same weapon system, if desired) that can be changed over time.

If the formal support system is to provide resources to bases in a way that is consistent with operational needs over the short run, it will often have to deal with the unexpected demands that, as we have seen, are likely to occur in the face of uncertainties. Under the current system, when local shortages or maldistributions across units develop, informal management adaptations such as redistribution, lateral supply, and lateral repair are often used to respond; however, such adaptive responses need to be more proactive (unless it can be shown that enhanced responses to events as they occur are sufficient to meet operational needs) and systematic than they now are. Such tactics, applied systematically and on a wider scale, can help the formal support system meet Operations' changing needs. This approach is based on the idea that the system needs to be flexible enough to provide the decisionmaker with levers to use in innovative ways. Thus, it is important in many circumstances, especially in wartime, to have a variety of well understood, well practiced management adaptations available. Redistribution, lateral supply, and lateral repair need to become well developed and well practiced mechanisms supported by visibility and decision support that make them systematic. These techniques are particularly important in solving the allocation/reallocation problems just discussed. The idea here is not simply to respond to MICAPs, but rather to be *proactive* in resource allocation, precluding MICAPs before they occur. Given the unpredictabilities that have been discussed, attempting to be proactive in an environment of long planning horizons and long response times would make no sense. But where response times are very short, then a proactive approach may be justified because the cost of recovering quickly from a wrong decision may be small. In particular circum-

stances there may not be a need to be proactive, for example when response times are very short or the scenario especially dynamic.

REQUIRED INFRASTRUCTURE

Orchestrating the short-horizons approach and responsive adaptations described above requires an advanced system for combat support command and control. The specification of goals, to take just one component, presents a significant challenge. The C^3 system must elicit requirements over the short run from Operations. If the requirements cannot be met, the next best options suitable to Operations need to be worked out. Likewise, if the infrastructure is to respond to near-real-time needs, it must have good visibility of resources. When making decisions about the components to be repaired in support of the combat forces, for example, very current information is required about the worldwide asset position as well as the current status of aircraft. Such visibility must be updated frequently[2] And the system must support the unit-theater-CONUS-worldwide perspective.

This element of the system, like other elements, needs to be able to respond appropriately to unanticipated events. It is inevitable that the system will need to act in degraded modes. Delayed and otherwise degraded information is likely to be a way of life in high intensity conflict involving enemy attacks against the infrastructure and its control system. Backup modes may be needed to sustain operations. Understanding the effects of particular kinds of information degradation on the quality of decisions is also important in the design of an effective and robust command and control system.[3]

Command and control systems are touched upon here; the means for establishing their goals, for example, is the subject of future reports. But in broad outlines, such a system would be especially concerned with eliciting aircraft availability goals from Operations, tasking the infrastructure appropriately, and assuring that corrective actions are taken when responses to the tasking are ineffective.

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[2]This attribute has special significance for repair organizations that are not collocated with combat units. Typically, collocated intermediate-level maintenance does not operate on the basis of long-run forecasts of the repair needs of supported organizations because they have first-hand, current knowledge of the state of the force. Issues of providing special visibility become important for noncollocated repair organizations. This situation is the case for depots. In such cases, the use of near-real-time data for repair decisions is critical.

[3]This issue is explored in Gustafson, op. cit.

If the infrastructure is to respond to near-real-time needs, it must also have the capability to respond to unanticipated, urgent demands, sometimes of unusual size. It might achieve such robustness by having resources that are able to respond to wide ranges of demand. Priority systems, for example, imply common resources, including both transportation and repair. If the repair resource, people or equipment, is *stovepiped*—i.e., dedicated to only one kind of asset—a priority system has no leverage. In such cases, there may be no way for the repair system to take care of unanticipated demands except to buy more repair capability or more stock. Yet, as we saw earlier, such attempts to buy out may result in considerable sums of money being spent to take care of unanticipated events that may never occur. An option may be to enhance the *scope of repair* by making repair resources common to a number of components. This can be achieved through investments in test equipment and other repair resources that can be used to repair many different kinds of components, for example, or by cross training personnel so that they are skilled in the repair of many components.[4] More or fewer of these common resources can be applied to satisfy urgent needs depending on how demands eventuate. It may be more cost-effective to invest in enhancing scope of repair than in trying to buy "sufficient" repair or spares to hedge against all of the uncertainty in demand.

THE CLOUT INITIATIVES

In pursuing the directions just outlined, we have developed a number of integrated initiatives that we call CLOUT: Coupling Logistics to Operations to meet Uncertainty and the Threat. The purpose of CLOUT is to integrate Logistics and Operations and to provide a number of management adaptations so that we can meet support demands responsively, despite many of these uncertainties.

Given the foregoing backdrop, a schema for the workings of a responsive infrastructure is provided in Figures 3.2 and 3.3. In the theater, for example (see Fig. 3.2), one might want to provide a MOB with the ability to support some COBs with lateral repair. In that case, the MOB would have to be sized, resourced, and managed so that it could respond to the intermediate-level repair needs of its assigned COBs. To reallocate assets in response to operational goals, a proactive lateral resupply system is needed that reallocates assets in very short

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[4]Gotz, G. A., and R. E. Stanton, *Modeling the Contribution of Maintenance Manpower to Readiness and Sustainability*, RAND, R-3200-FMP, January 1986.
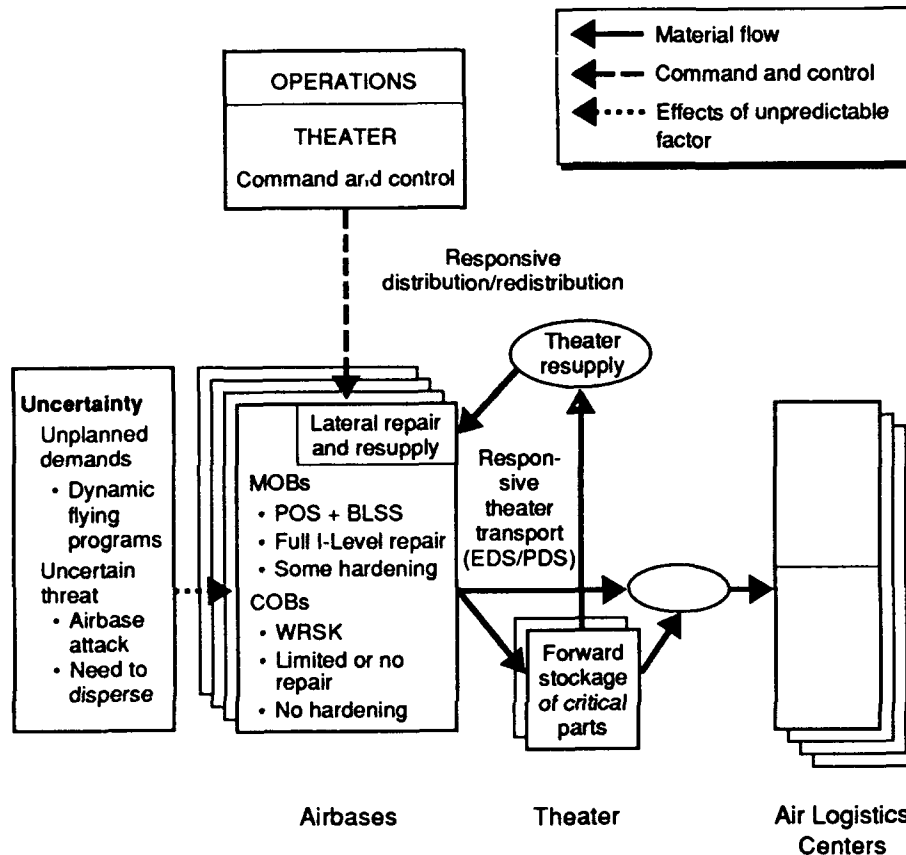
Fig. 3.2—CLOUT: Enhancing Theater Responsiveness

times. Such characteristics imply a more advanced European Distribution System (EDS) and a more advanced Pacific Distribution System (PDS).[5] In this context, for example, a more advanced EDS is one that not only responds quickly to MICAPs but attempts to preclude them, and it would recognize that operational needs at the bases may be dynamic, so quantities of resources at the bases may have to be adjusted quickly in accordance with this need. Those deci-

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[5]The EDS was the intratheater transportation system of the U.S. Air Forces Europe; the PDS was the proposed intratheater transportation system of the Pacific Air Forces.
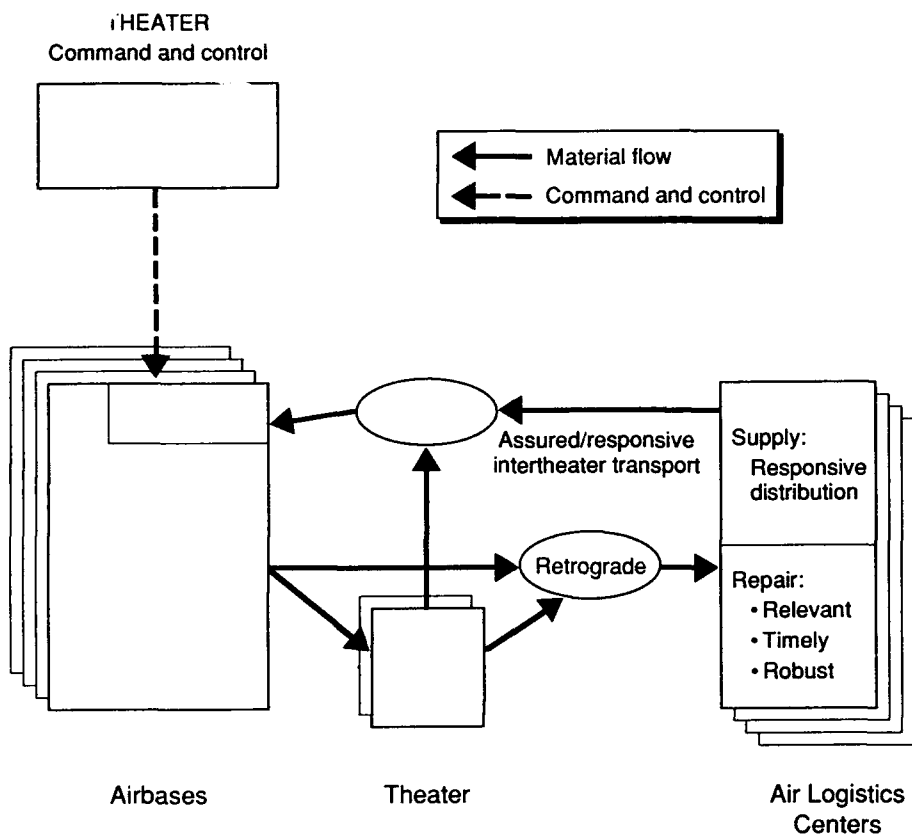
Fig. 3.3—CLOUT: Enhancing Depot Responsiveness

sions need to be in the hands of the operations and combat support controllers. Their wisdom will be required to avoid excessive turbulence in the system that could conceivably result from rapidly changing goals and priorities.

To enhance the depot's responsiveness (see Fig. 3.3), assured and responsive intertheater lift must be available, not just for moving serviceables to the theater, but for returning parts to be repaired. Both supply and distribution will be based on theater needs, as defined by current information.

In addition to these initiatives, there might be payoff from establishing an intermediate-level repair facility somewhere in the rear: for example, in the UK or Portugal.[6] A kind of "Queen Bee" concept—after the fashion of consolidated jet engine field maintenance arrangements of the past. where one base might support 120 or so aircraft—is also a promising alternative. Locating a limited depot capability in the theater to complement the CONUS depot capability may also have advantages.

Figure 3.4 places this infrastructure into the context of a command and control system. If the theater command and control system has near-real-time asset information and can specify availability goals for each base and change those goals from time to time to reflect operational urgencies as they unfold, we can develop algorithms to allocate resources or assign priorities over short planning horizons to maximize the chances of achieving the goals. For example, the algorithm could advise the MOB how to sequence repairs of components to provide relevant, timely support to the COBs as well as to the MOB itself, thus contributing most effectively to meeting the operational goals. The same logic applies to theater distribution. The allocation and reallocation of components should also be based on maximizing the probability of achieving the aircraft availability goals.

The depot problem has substantial similarity to the theater problem. Information about availability goals by base, and information about the near-term flying program as well as the worldwide asset position, can provide the needed priorities. In this case, we have actually written a prototype assignment algorithm. Called DRIVE (Distribution and Repair In Variable Environments), it determines the priorities for the component repair system and for the distribution system so that maximum support is provided according to the availability criteria.[7] More is said about the DRIVE prototype in Sec. 5.

Damage and disruption are likely to involve the need for allocating and reallocating spares and other resources. The advanced command and control system needs to be able to support the decisionmaking that will be required in such circumstances. Another anticipated situation that the command and control system should be able to help manage is that in which aircraft land at bases other than their home bases. Aircraft may be pinned out of their bases as a result of enemy

[6]During this study there were particular reasons for considering Portugal.
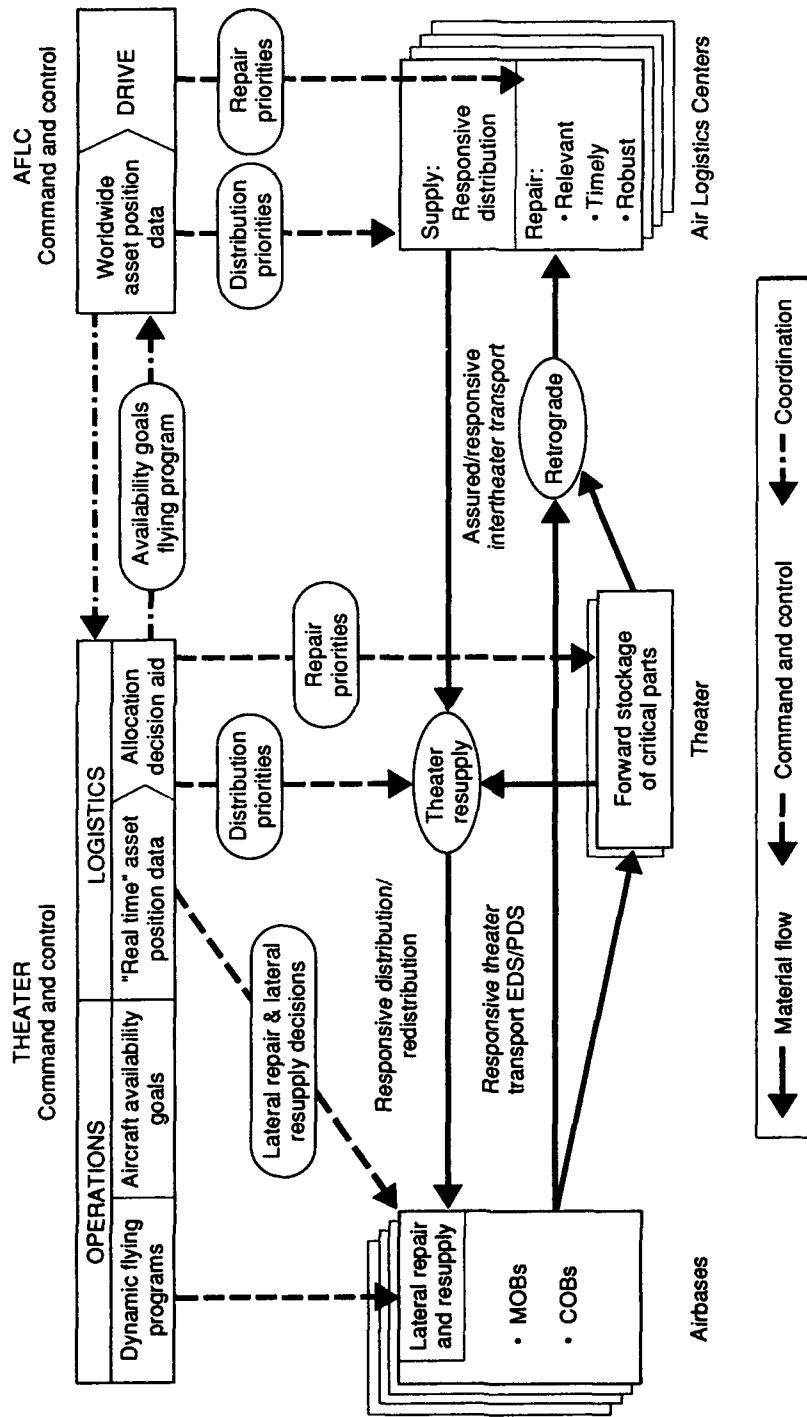
[7]Abell et al. and Miller and Abell, op. cit.

Fig. 3.4—CLOUT: Command and Control System

attacks. Under such circumstances, it may be a matter of considerable urgency to be able to launch combat sorties from locations other than home base. There may also be other reasons for Operations to have the flexibility to operate away from home base for short periods. In such situations too, the allocation and reallocation of spares and repair are likely to need to be extended to other resources.

Figure 3.5 reminds us that CLOUT is not just combat support operations. We need to include notions of uncertainty and the system's adaptations to uncertainty in each stage of the PPBES. We have selected the execution phase for initial review and change, in part because it might be argued that planning, programr.ing, and budgetary systems need to reflect the essence of the execution system. Certainly if each stage is to be integrated with the others, explicit consideration of uncertainty and management adaptations should be common to all of them.

RAND is also exploring ways to incorporate explicit consideration of uncertainties and management adaptations in requirements systems. With an upgraded requirements system, the programming and budgeting stages of the PPBES will become consistent with the suggested execution and planning stages. As mentioned earlier, a study is also being formulated to develop and demonstrate multiechelon spares and repair and financial management systems for the Air Force that are intended to explore additional means for implementing lateral repair, lateral supply, and priority repair.

Secs. 4 and 5 provide more concrete views of the CLOUT initiatives. Evaluations of some of the CLOUT initiatives are also reported. It should be emphasized that even in the spares, repair, and transportation areas, CLOUT needs extensions. The representation of uncertainties that the logistics system may face in wartime also needs improvement in those decisionmaking processes involving irreducibly long lead times. Additional initiatives need to be identified for potential use in making the logistics system more robust in the face of peacetime and wartime uncertainties and the dynamic support needs of Operations. Moreover, CLOUT's orientation needs to be extended to resources beyond spares, repair, and transportation. For example, munitions management is clearly a logical extension to the thinking underlying the CLOUT initiatives. Munitions availability could be improved through systematic reallocation when demands evolve in unanticipated ways owing to changes in planned targets or unexpected rates of expenditure. A very responsive industrial base could be another important management adaptation for dealing with uncertainty in this context.

THEATER
Command and control

AFLC
Command and control

DRIVE

Worldwide asset position data

Repair priorities

Distribution priorities

Supply:
Responsive distribution

Repair:
• Relevant
• Timely
• Robust

Air Logistics Centers

OPERATIONS

Dynamic flying programs

Aircraft availability goals

LOGISTICS

"Real time" asset Allocation

More Than Logistics Operations

• Planning
  – System evaluation
  – Need to assess responsiveness for planned and unplanned scenarios

• Requirements
  – Spares
  – Depot repair

of critical parts

Theater

Lateral repair and resupply

Lateral repair and resupply

• MOBs
• COBs

Airbases

Material flow
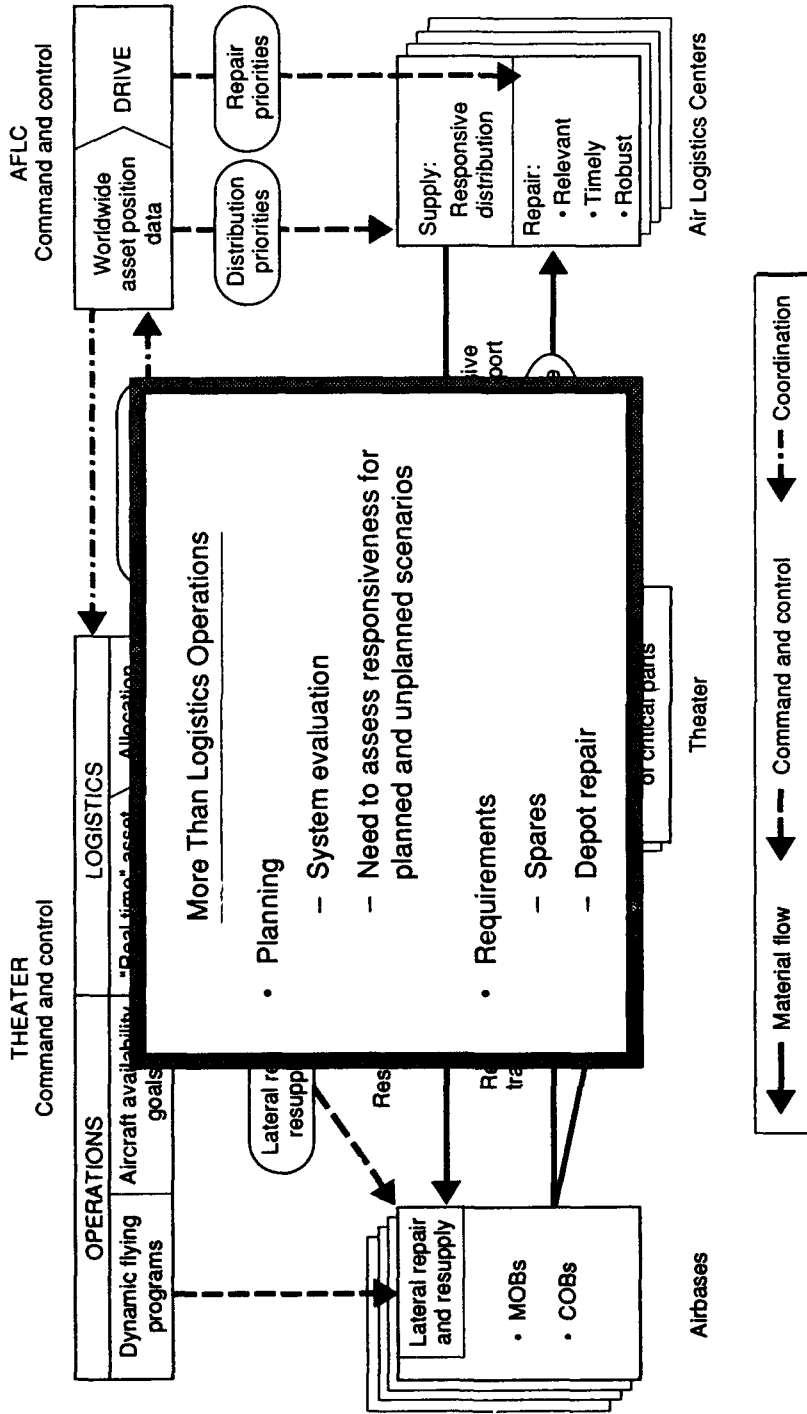Command and control
Coordination

Fig. 3.5—CLOUT: The Larger Context

4. AN ASSESSMENT OF CLOUT

In this section we explore, under a variety of wartime scenarios, some of the potential payoffs of the responsive and robust CLOUT initiatives discussed in the preceding section.

These scenarios reflect wartime resource demand uncertainties, some postulated effects of battle damage, and the potential need for more flexible wartime basing options. We focus primarily on the theater CLOUT initiatives, but we also consider how a responsive CONUS depot repair system with a comparably responsive intertheater transportation system might also contribute to enhanced system performance.

Our principal findings are as follows:

- Current planning for wartime combat support does not take sufficient account of the uncertainties of potential wartime requirements and scenarios.
- The CLOUT initiatives can help absorb and mitigate the effects of such uncertainties and the effects of battle damage as well.
- CLOUT enhances the ability of the logistics system to support alternative basing strategies and dispersed operations.

CAPABILITY ASSESSMENT TOOLS

Capability assessment tools are central to the planning process. Enhanced tools (in light of CLOUT) are in development and in prototype use at RAND. In the past few years, there have been advances in analytic evaluation models. They use more appropriate criteria, such as available aircraft or sorties, and they incorporate a wide range of wartime dynamics in terms of changes in flying programs or how the force is phased into the war.

However, there are serious shortcomings in the way most capability assessment models handle repair, and as we have seen, repair is critical to CLOUT. Essentially, these models allow repair time to be independent of workload in a shop. Effectively, this provides unconstrained repair capacity, a very inappropriate assumption for some critical shops. The current models do not use the more advanced kinds of priority systems. Moreover, they do not deal with priority distribution. Nor do they represent the lateral supply or lateral repair capabilities that we have been discussing.

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RAND's development in this area is intended to provide initial attempts to overcome these limitations. Indeed, we must have them if we are to evaluate the CLOUT initiatives (management adaptations) against different levels of uncertainty. To date, we have focused our efforts on avionics repair. These prototype developments need to be evaluated for their applicability to the repair of other aircraft systems.

The RAND models cover two assessment scenarios: theaterwide assessments and repair shop assessments. This section incorporates some of the results from the first model, called Dyna-METRIC Version 5.[1] Another model, Dyna-SCORE, was used in exploring management initiatives in depot-level component repair.[2]

DETAILS OF THE CLOUT INITIATIVES

In the paragraphs that follow we discuss our approach to evaluating the CLOUT initiatives and clarify our assumptions.

Reactive and Proactive Lateral Resupply

The Air Force has established a goal of 1.5 days as the time required for the European Distribution System (EDS) and the proposed Pacific Distribution System to move an asset from one base in theater to another. Although the goal is the same in wartime and peacetime, for evaluative purposes we used a two-day in-transit time. Currently the EDS causes a lateral resupply action to occur only when an aircraft is not fully mission capable (NFMC) at one base and another base has the needed part—i.e., the system is *reactive*. CLOUT envisions *proactive* lateral resupply made feasible by near-real-time visibility of the asset position at all bases in the theater, coupled with very short response times and a more sophisticated command and control system as suggested in Sec. 2. In particular, when possible, we ship a part from one base to another to preclude an airplane being kept down for lack of the part rather than waiting for the shortage to occur before shipping.[3]

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[1]Isaacson and Boren, op. cit.

[2]Tsai, op. cit.

[3]A simple zero-balance rule was used: if one base has no serviceable asset and one or more other bases can give up an asset (and more than one serviceable is on hand), we ship from the "richest" base. In this analysis we treat all bases with the same Mission Design Series (MDS) with equal priority. The DRIVE algorithm, briefly discussed in Sec. 3, has the potential to provide even better decision support, and to deal explicitly with differential priorities across bases as discussed in Sec. 1.

Lateral Repair

The intermediate-level priority repair and distribution rules we used are based on a theater criterion: maximizing the number of aircraft in the theater that are fully mission capable.[4]

Responsive Depot Support

The analysis includes responsive depot resupply of test equipment parts as well as aircraft components, i.e., line replaceable units (LRUs). Test equipment parts are critical in keeping intermediate repair facilities in the theater operational, and, typically, the depot is the only source of supply when local stocks are depleted. Because of modeling constraints we do not model the depot resupply of LRU repair parts; therefore, we underestimate the potential payoff of a responsive depot system. We model the depot only in terms of resupply time because we cannot, at the present time, model priority depot repair and distribution.[5]

SCENARIO AND SCOPE OF ANALYSIS

Our scenario is basically a NATO wartime scenario. The measure of effect is the percent of aircraft not fully mission-capable (NFMC) at the end of the first 30 days of conflict. We chose this performance measure because it is more demanding than a measure of partial mission capability and somewhat more sensitive to inventory system performance. We will examine three cases: (1) one in which there is a more realistic level of demand uncertainty but no battle damage; (2) one in which there is differential damage to spares and repair facilities across bases due to airbase attack; and (3) one involving an alternative basing strategy but no damage.

The analyses focus exclusively on F-15 and F-16 avionics LRUs that are included in the range of the WRSK. Avionics components tend to be both cost drivers and the primary cause of NFMC aircraft.

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[4]The model used in these analyses would not reallocate an asset to a base through lateral supply if an asset were already enroute to the base from the depot. The priority repair rule used was rather sophisticated. If lateral supply was not in effect, it prioritized the repair of assets to alleviate shortages first at the base with the highest proportion of its aircraft NFMC. With lateral supply, it prioritized the repair of the assets with the most shortages theaterwide. If no shortages existed, it prioritized the repair of assets with the earliest anticipated shortages. Lateral repair did not involve a centralized intermediate repair facility, only a main operating base.

[5]Our models are currently being changed to model depot repair and distribution more faithfully.

Assessments with Dyna-METRIC show that more than 75 percent of the aircraft down are NFMC because of avionics.[6] Avionics components constitute more than 80 percent of the cost of a typical WRSK.[7]

The item demand data were extracted from WRSK listings maintained by Headquarters, AFLC. Bench check serviceable (BCS) rates were estimated from data extracted from the maintenance data collection system. Wartime flying programs are the same as those used in computation of the WRSK requirement by Headquarters, AFLC.

We have represented demand uncertainty in four ways: First, the base case represents the standard Air Force wartime planning assumptions with a VTMR of 1.0 for all components. Second, we have also included what we call *fault isolation* uncertainty. Frequently, a maintenance technician removes what he believes is a failed component from an aircraft on the flightline and sends it to the intermediate-level maintenance shop to be repaired. In the shop the component is placed on the test stand but no malfunction is found. These BCS removals are not counted in the supply system; therefore, they are not counted in the standard estimation of component demand rates used in computing peacetime and wartime spare parts requirements. In peacetime, BCS actions constitute about 30 percent of all avionics removals worldwide, but the rate varies greatly among bases and components.[8] Third, we used actual peacetime VTMRs for major components.[9] They range from 0.75 to 5.0 for individual components, but equivalent performance (percent NFMC on day 30) is obtained if the VTMR for all components is set to about 3.0. Fourth and finally, we considered the case where the VTMR of every component is set equal to 4.0 to reflect the additional uncertainty in the demand for spare parts that may be experienced in wartime.

Avionics intermediate-level maintenance is available at all F-15 bases, along with a test equipment spares kit (separate from the

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[6]Dyna-METRIC Version 5, the capability assessment model used in these evaluations, is described in Isaacson and Boren, op. cit.

[7]Simple examination of WRSK listings on the AFLC CREATE computer system reveals this.

[8]Source: AFLC D056 data system using data from 1985 and 1986. In wartime and in peacetime exercises simulating wartime, flight line mechanics may be more careful in the face of supply shortages or the lack of an intermediate-level repair facility. They may swap what they believe are good components in and out of the aircraft before declaring that a particular component has failed. Such adaptive behavior is difficult to model or predict, so we assumed peacetime BCS experience for this analysis.

[9]The source for the VTMR estimates was also D056 data from 1985 and 1986.

WRSK or BLSS).[10] In the F-16 case, intermediate-level avionics maintenance is available only at main operating bases (MOBs), with test equipment spares support available only from standard POS and BLSS stocks. In this analysis we assume that there is no intermediate-level repair taking place at the F-16 collocated operating bases (COBs), and that they have to rely solely on their WRSKs.[11] It is assumed that all WRSKs are full at the start of the war.

Version 5 of the RAND Dyna-METRIC model used in this analysis incorporates the lateral resupply rules and repair priority rules we have already described. The model assumes full cannibalization of LRUs at the flight line to minimize the number of NFMC aircraft due to supply shortages—i.e., it assumes that *every* component of the aircraft can be removed and installed on another aircraft. The model also reflects test equipment failures and the resupply of test equipment parts from the depot (if available). If the right part is not available to fix the test equipment, that test stand becomes partially capable in that it can repair only that subset of the LRUs not affected by the missing part (or parts). If two or more test stands of the same type are at a particular location, the model allows cannibalization of parts from the stands so that the greatest range of LRUs can be repaired on at least one of the stands.

No less than 50 replications of a 30-day war underlie each of the results portrayed in the graphs that follow. The results shown are actually means of the 50 or more experimental replications. In those cases where the NFMC rate is high, i.e., 40 or 50 percent, the experimental error is higher than when the outcome is, say, 15 or 20 percent. To gain some intuition about the role of experimental error in this analysis, consider the fact that with 50 replications, an NMCS rate of 30 percent can be expected to vary between about 28.4 and

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[10]Special Purpose Recoverables Authorized to Maintenance (SPRAM), a kit of repair parts valued at about $8 million, is separate from the WRSK. This kit has greatly improved repair performance at bases where there is only a single avionics test stand; with two test stands but without such a kit, cannibalization is typically required to keep at least one test stand fully operational. A SPRAM kit was used in Coronet Warrior I. Further discussion of this topic can be found in Pipp, Capt. D., USAF, "Coronet Warrior—A WRSK Flyout," *Air Force Journal of Logistics*, Summer 1988.

[11]This is consistent with Air Force planning for wartime in the F-16 case. As discussed earlier, flightline mechanics at COBs may, in wartime, become more inventive in the face of supply shortages and use an airplane that is already down for some other reason as a hot mockup to perform limited intermediate-level maintenance on failed components. Such behavior has been observed in F-16 peacetime exercises simulating wartime. Again, such adaptive behavior, called "shade tree maintenance" by some, is difficult to predict and to model. See Viccellio, H., Maj. Gen., USAF, "Coronet Warrior II," briefing given to the Air Force Logistics Conference, 1988.

about 31.6 percent roughly 95 percent of the time. This result depends on the number of aircraft in the scenario as well as the mean proportion of aircraft NMCS; nevertheless, it is safe to say that the experimental error associated with these analyses is sufficiently small that it alone does not account for the magnitude of any of the differences in system performance portrayed in this section.

Many different cases were examined during the course of this work. We have selected for inclusion here only a few that we felt were illustrative of the performance gains that can be achieved with the CLOUT initiatives, not necessarily those that had the most improved performance. It is important to note that there was no case in which performance did not improve as a result of the CLOUT initiatives, although, clearly, one can postulate scenarios that tend to defeat them. For example, if there were only one base having aircraft of a particular type in the theater, the value of lateral supply or lateral repair would be sharply reduced, since it only applies to items that are common to aircraft at more than one location. Ignoring such pathological exceptions, it is reasonable to say that these adaptations always pay off in terms of improved system performance.

CLOUT PAYOFFS WITH WARTIME DEMAND UNCERTAINTY AND NO DAMAGE

We begin our description of the CLOUT payoffs by considering the effects of realistic levels of demand uncertainty on aircraft availability. The scenario involves 144 F-16s, including one MOB with a wing of 72 aircraft, and three COBs, each with a squadron of 24 aircraft. The MOB has two sets of avionics test stands, the normal allocation of primary operating stocks, plus the wartime increment (BLSS). The COBs have no intermediate-level repair capability, but each has a remove-and-replace WRSK. Consistent with standard Air Force planning for wartime, there is no depot resupply for the first 30 days of the war. Figure 4.1 shows the effects on system performance of explicitly accounting for fault isolation uncertainty and more realistic levels of demand variability.

Given the standard Air Force planning assumptions (demand rates observed in peacetime and a VTMR of 1.0), about 14 percent of the 144 aircraft will be down on day 30.[12] If we take account of fault

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[12]At the time of this analysis (1986) the design support objective (DSO) for the WRSK was 4 out of 24 aircraft NFMC (or about 17 percent) for all components (not just
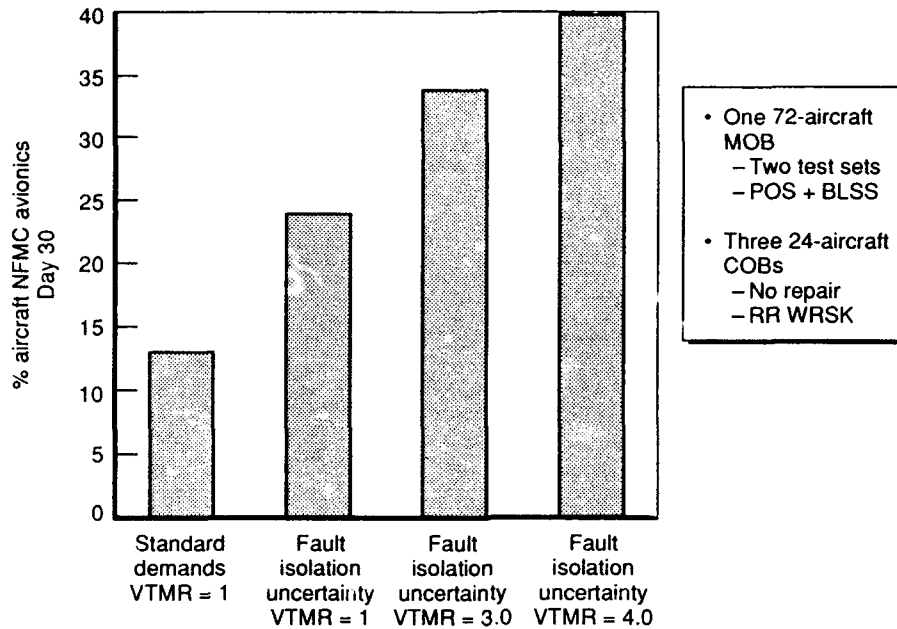
Fig. 4.1—Effects of Uncertainty on F-16 Aircraft Availability

isolation uncertainty, the NFMC rate rises to almost 25 percent. If we include the actual observed peacetime VTMRs (roughly 3) in addition to the fault isolation uncertainty, more than 30 percent of the aircraft are down. If we use a VTMR of 4.0 to reflect some of the additional uncertainties of wartime, 40 percent of the aircraft are not fully mission capable due to avionics by day 30. As we suggested in Sec. 1, the effects of demand uncertainty can be significant.

Figure 4.2 shows how CLOUT counters the effects of demand uncertainty. For easy reference, the left side of the figure reproduces the data in Fig. 4.1. The responsive, proactive lateral resupply system previously described substantially reduces the NFMC percentage. The expected number decreases from almost 40 to just over 25 percent. If the MOB also does intermediate-level priority repair for the COBs as well as for its own aircraft, the percent of aircraft NFMC is reduced to about 20 percent.

avionics) on day 30 of the conflict. Since that time, the DSO has been increased to 6 out of 24 (or 25 percent) NFMC.
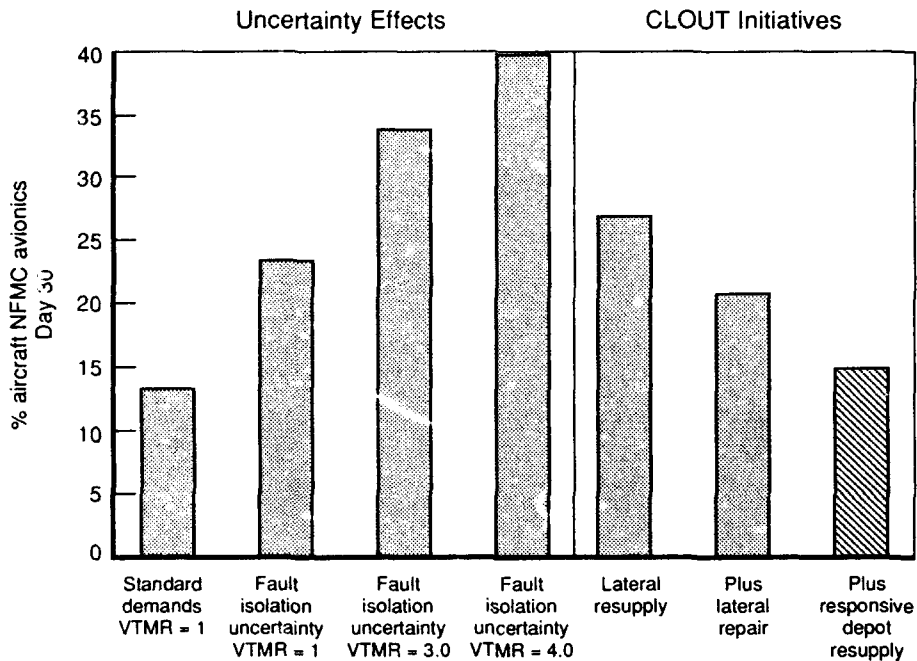
Fig. 4.2—Responsive Support Pays Off in a "Benign" Environment

Note that the repair capability at the MOB was intended to support only 72 aircraft with its two sets of test stands under standard Air Force planning assumptions. With the lateral repair initiative in place, it is now supporting 144. Although MOB repair is saturated, because the base is using priority repair—repairing the most important items—its repair capability still makes a significant contribution.[13] In addition to these gains, if the depot and intertheater transportation can respond with 10-day resupply times on average, they can reduce the number of aircraft NFMC (for avionics) to approximately 14 percent, roughly the original planning objective. The depot contributes to this reduction by absorbing the uncertainty in demand for the components that are beyond base-level repair capability

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[13]The repair capacity of the MOB was not assumed to change in this illustration, to show the payoff of lateral repair with existing numbers of test stands.

as well as by supplying the test equipment parts needed to keep the MOB's maintenance activity fully operational.[14]

Concern has been expressed about the availability of airlift to meet the needs of a responsive depot system, especially during the early days of a NATO scenario. Table 4.1 shows the airlift requirement in pounds of cargo per day each way to transport all LRUs beyond normal base repair capability (excluding engines) for all F-15 and F-16 units in a NATO conflict. The estimates assume wartime flying-hour rates and peacetime NRTS rates. Although these estimates are subject to uncertainty, they are reasonable approximations. The tonnage shown requires less than two C-141-equivalent sorties per day during the early surge period of the scenario, and less than one during the following sustainability period. Since the vast majority of critical components can be loaded aboard narrow-doored aircraft, unmodified Civil Reserve Airlift Fleet (CRAF) aircraft might be likely candidates to fill this airlift requirement. The transportation requirement to couple the depot more closely to the operational force is modest, and the potential payoff is significant in terms of combat capability.

These results show that the CLOUT initiatives help mitigate the effects of significant levels of demand uncertainties in wartime. They also enhance system performance in the face of battle damage.

CLOUT SUPPORT IN THE FACE OF BATTLE DAMAGE

Another major source of wartime uncertainty derives from enemy air attacks against our bases. Past simulation studies of such attacks suggest that collateral damage of critical logistics resources, e.g.,

Table 4.1

**F-15 and F-16 Depot Repair Airlift
Requirements
(pounds per day each way)**

NATO Region	Surge Period	Sustain Period
North	6900	3000
Central	26000	12000
South	10000	4000
Total	42900	19000

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[14]Recall that we are underestimating the depot's potential contribution in this analysis because we are not representing the demand for SRUs for which the depot is the primary supplier.

spare parts and avionics intermediate shops (AISs), is likely. Typical Warsaw Pact regimental air attacks against three F-15 bases— Bitburg, a MOB with 72 aircraft and two sets of test stands; Lahr, a COB with 48 aircraft and two sets of test stands; and Sollingen, a COB with 24 aircraft and a single set of test stands—were modeled to assess their effects on system performance with and without the CLOUT initiatives. The attacks were primarily targeted against runways and aircraft in the open and in shelters. All bases were modeled with aircraft shelters. Critical support resources such as spares and avionics test equipment were dispersed in shelters or in their own hardened facilities.[15] Figure 4.3 shows the range of expected losses for aircraft, spares, and AISs at each base for 10 Monte Carlo trials of the same attack size and profile. The small square superimposed on each of the vertical lines represents the average for the 10 trials. These results suggest that the nature and extent of dam-
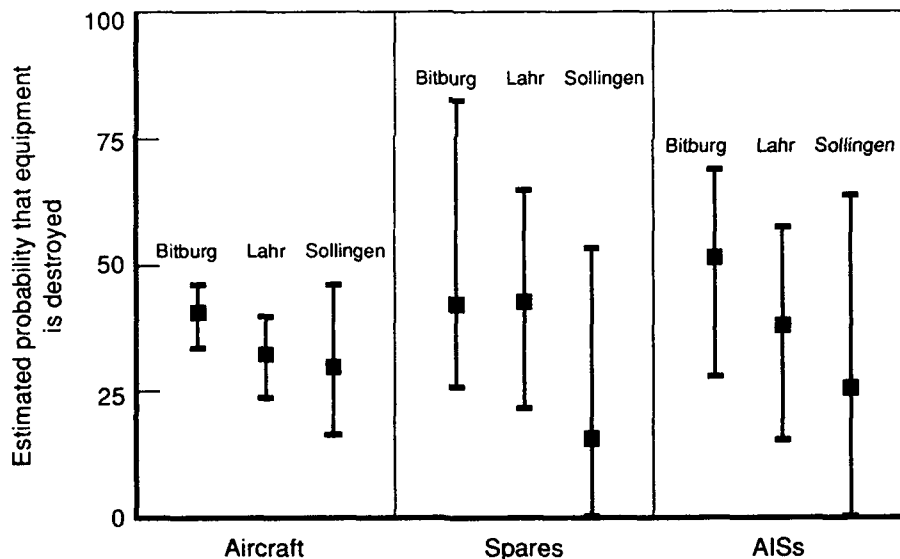

Fig. 4.3—Range of Airbase Attack Damage
(10 Monte Carlo trials: same attack size and profile)

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[15]Dispersal of support resources followed patterns developed in USAFE's Salty Demo Exercise, an airbase survivability test held at Spangdahlem AB, Germany, in 1985.

age induced by airbase attack, even when the attack size, profile, and targets (i.e., aiming points) are specified, are very unpredictable.

Figure 4.4 shows the same data as 4.3 but also shows the outcome of one particular replication. Note that at Lahr there was a high probability that the AISs would be damaged, while there was a low probability that spares would be lost.[16] Sollingen, on the other hand, had a low probability of losing its AIS, and a high probability of losing spares. The implications are important. Although the logistics system attempts to provide a balanced mix of resources among bases at the beginning of a conflict, after such an attack there is likely to be an imbalance of resources across bases—that is, some bases may be relatively rich in a particular resource while others may face a paucity of
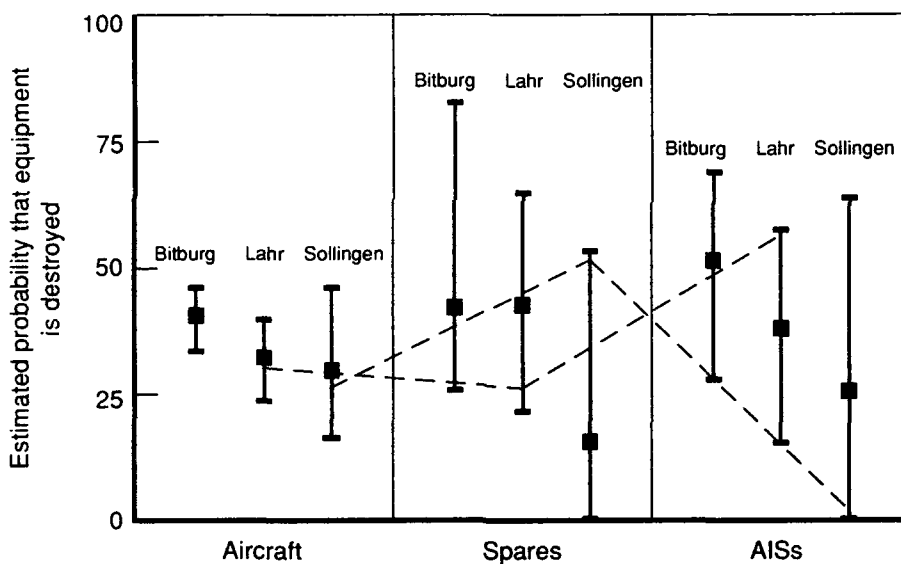
Each dashed line represents a single replication.

Fig. 4.4—Outcomes of Two Particular Replications

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[16]For aircraft and spares, losses in a single replication either occur or do not occur. The number that occur is represented as a proportion of the total and is viewed as an estimate of the probability of loss of individual assets. The AISs were treated differently here. They were enclosed in shelters, and if a bomb fell within the shelter, it was assigned a probability of destroying each AIS according to the locus of the hit.

it. Such imbalances diminish system performance and reduce sustainability.

Figure 4.5 shows the performance of the current system and the CLOUT initiatives with no battle damage in one case and, in the other, with the expected damage from the attack series shown in Fig. 4.4. The graph portrays the results for the loss of two AISs, one at Lahr and one at Sollingen, and results for the loss of one AIS, at Lahr. In the case where two AISs are lost and the CLOUT initiatives are in place, Sollingen is supported by lateral repair at Bitburg, while Lahr must live with its one surviving AIS. In the case of one AIS loss at Lahr, it must live with its one remaining AIS. CLOUT provides for lateral resupply. No lost resources are replaced from CONUS for the first 30 days. The leftmost bar in Fig. 4.5 shows that with no attack and wartime demand uncertainties, more than 20 percent of the aircraft will be NFMC due to shortages of avionic parts. Note that F-15s
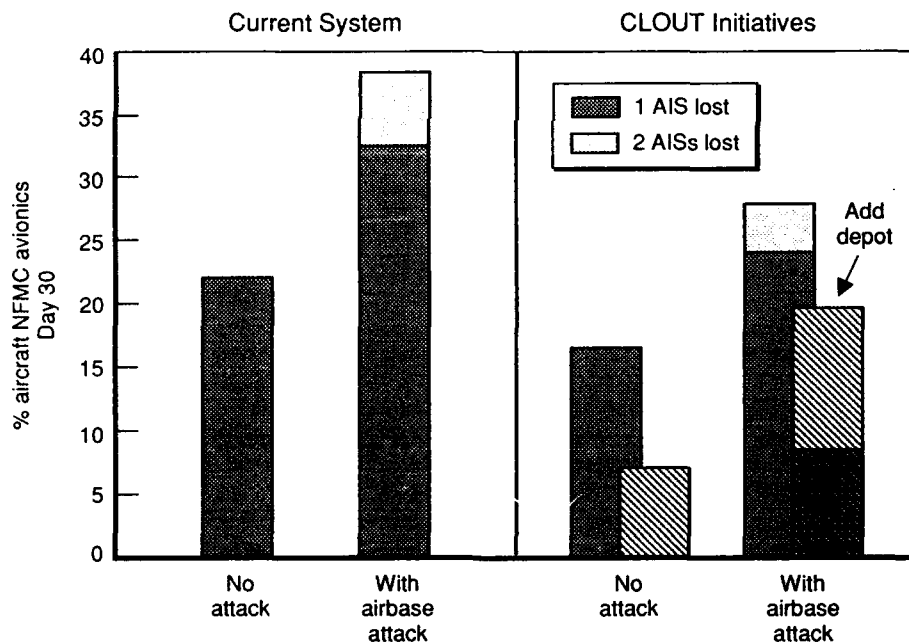

Fig. 4.5—CLOUT Payoffs with Base Damage
(F-15s: 72-aircraft MOB, 48-aircraft COB, 24-aircraft COB)

perform better than the F-16s because they have priority intermediate-level repair available to absorb the demand uncertainties. The second bar shows the effect of battle damage with no CLOUT initiatives in place: almost 40 percent of the aircraft are down by day 30 if two of the five AISs are lost.

With the CLOUT initiatives there is significant improvement even in the no-damage case, a reduction from more than 20 percent to about 15 percent NFMC without depot support. With responsive depot support we would expect only 5 percent down. The depot makes more of a difference in the F-15 case because the F-15 has a higher not-repairable-this-station (NRTS) rate than the F-16. F-15 units are also more dependent in wartime on the AISs for repair of LRUs because every unit deploys with at least one AIS and a remove-repair-and-replace (RRR) WRSK, which has fewer LRUs and more repair parts than the F-16 WRSK. As a result, the depot resupply of critical test equipment parts has a larger payoff in the F-15 case.

With the CLOUT initiatives in place in the face of battle damage, the expected NFMC rate drops from almost 40 percent to about 30 percent if two AISs are lost. If a responsive depot system is in place as well, the NFMC rate on day 30 is reduced further to about 20 percent in the case of two AISs lost. This is about the best the system can be expected to do with three surviving AISs, because the repair capacity is totally saturated. As in the case of the F-16 MOB, priority repair makes the most of the surviving AISs. If only one AIS is lost, responsive depot support will put this three-base complex in a better position even with battle damage than it would have been in with no damage but no depot support in the first 30 days. Clearly, the CLOUT initiatives can significantly improve logistics support in the face of battle damage to support resources.

CLOUT SUPPORT OF ALTERNATIVE BASING OPTIONS

In wartime it may be desirable or necessary for aircraft to operate from bases other than their home bases. This is another source of uncertainty in combat, and the logistics system must be sufficiently adaptive to provide effective, continuing support to such aircraft. This adaptability also gives operations the flexibility to exercise alternative basing options.

There are several reasons why such flexibility might be required. Examples include reaction to airbase attack, dispersal in anticipation of attack, better staging for particular missions, the need to form composite wings, or even political considerations. Aircraft that are

airborne when an attack occurs may be forced to recover away from their home bases. If the aircraft are then unable to return to their home bases quickly, it might be important for them to be able to fly combat sorties from the alternative locations. In other cases, runways could be so severely damaged that aircraft would have to change operating locations for extended periods even though the support facilities at their home bases were still operational.

The requirement to disperse in high-threat environments like NATO is frequently discussed. The primary motivation is to spread the force or to move rearward to reduce vulnerability. Such dispersals may be for relatively short periods or for longer times, with aircraft returning to home base only for major maintenance. An example of the latter case would be to disperse the F-15 air defense force by deploying two-aircraft or four-aircraft flights to a large number of bases. Temporary or more permanent basing changes could also be motivated by mission requirements such as range-payload requirements, turn rate considerations, or a threat concentration in a different region.

Temporary or permanent composite wings may also be a desirable basing option. Again, they could be used to spread the force (of a particular type of aircraft) to reduce vulnerability or to facilitate attack packaging (more than one MDS), easing command and control and coordination problems. An example of the latter that has been implemented is the F-4G/F-16 operation at Spangdahlem AB in Germany. There may be other examples in the deep strike area.

The point here is that as the wartime situation unfolds, it may be necessary for a variety of reasons to support aircraft flying combat sorties from locations other than their home bases. The logistics system should be flexible and responsive enough to provide Operations as much basing flexibility as possible. The CLOUT initiatives have the potential to provide such flexibility.

Figure 4.6 shows a possible dispersal option for the same configuration of F-16 bases shown in Fig. 4.2 (a 72-aircraft MOB and three 24-aircraft COBs). In this case, each COB disperses a 12-aircraft unit with half the spares in its WRSK. The MOB is now supporting seven bases. The bars on the left reflect the performance of the current system with the original MOB and three COBs; with fault isolation and wartime demand uncertainty (no battle damage), 40 percent of the aircraft are NFMC on day 30. With dispersal, almost 50 percent of the aircraft are NFMC.
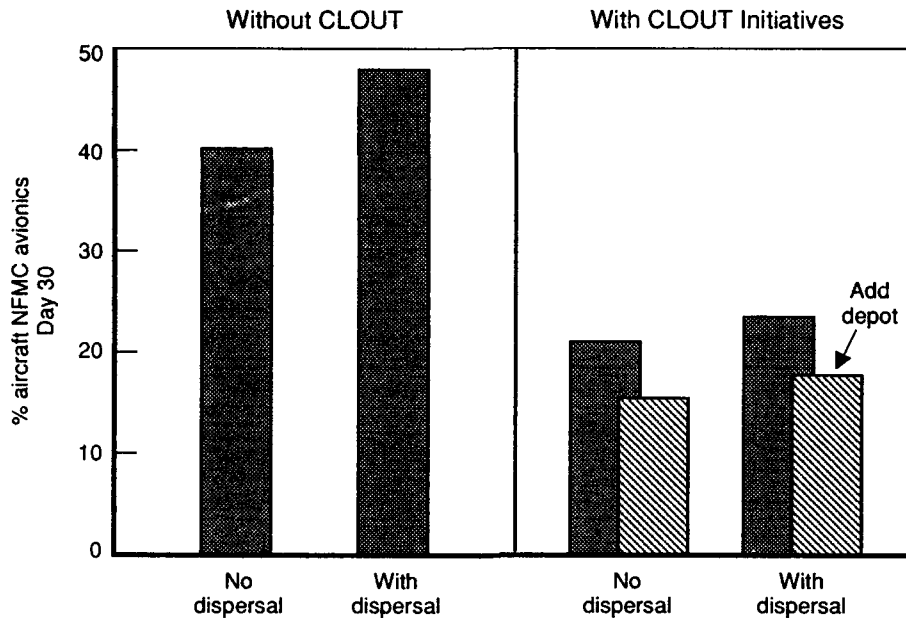
Without CLOUT   With CLOUT Initiatives

50

40

% aircraft NFMC avionics
Day 30

30

Add
depot

20

10

0

No   With   No   With
dispersal   dispersal   dispersal   dispersal

Fig. 4.6—Payoffs of CLOUT in Dispersed Operation
(F-16s: 72-aircraft MOB, six 12-aircraft dispersed operating bases)

The right-hand side of the figure shows the same cases with the CLOUT initiatives in place, lateral resupply and repair, and responsive depot support. The left bar in each pair reflects the CLOUT performance without dispersal; the right bar shows the CLOUT performance under dispersed operation. Note that dispersal under CLOUT degrades system performance very little. These data suggest that the performance of the system with the CLOUT initiatives is very robust—i.e., it is not particularly sensitive to basing options.

A SUMMARY OF THE CLOUT ASSESSMENTS

These assessments suggest the magnitude of the effects of wartime uncertainties on logistics system performance and demonstrate the potential payoff of a responsive and robust support system represented by the CLOUT initiatives. They clearly demonstrate the potential payoff of CLOUT in making the most of available resources worldwide in the face of the shortages and maldistribution that are virtually inevitable in wartime. Although the payoffs of the CLOUT initiatives have been evaluated and discussed in a wartime context

here, they also help mitigate the effects of asset shortages that arise in peacetime.[17]

These assessments have not been exhaustive, nor were they intended to be. For example, we did not show the effects of our inability to forecast wartime flying activities, which are likely to be far more dynamic and unpredictable than current planning assumptions. We assumed that units deployed with full WRSKs. In reality, they may not be full for a variety of unpredictable reasons, such as funding constraints, transportation constraints, or longer procurement lead times than anticipated. In each of these cases we believe that CLOUT would again show significant payoff.

We summarize the results of the CLOUT assessments as follows:

- Lateral resupply and lateral repair pay off, and theater priority repair helps mitigate the effects of demand uncertainty even when repair is saturated.

- Responsive depot resupply pays off. It, too, helps mitigate the effects of uncertainty in demand for items that are beyond base repair capability, and it supplies needed test equipment parts. Indeed, we underestimated the depot payoff in this analysis because we did not include responsive resupply of repair parts or the depot's ability to absorb base repair overflow and respond to damage.

- CLOUT initiatives better support alternative basing strategies and reduce the effects of damage and disruption.

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[17]A discussion of the effectiveness of some of the CLOUT initiatives in mitigating the effects of asset shortages in peacetime is contained in Abell, John B., and Thomas F. Lippiatt, *Effective Logistics Support in the Face of Peacetime Resource Constraints*, RAND, N-2921-AF, June 1990.

5. SOME EXTENSIONS OF THE CLOUT LOGIC TO OTHER APPLICATIONS

As suggested throughout this report, in decisionmaking about resource allocations or support strategies, the more dependent we are on accurate forecasting, the more vulnerable our solutions tend to be to the future evolving in ways that we did not predict. In problems involving relatively long planning horizons, forecasting tends to dominate the solution more than in problems involving relatively short planning horizons. The shorter the planning horizon, the more the solution is dominated by current circumstances and the less it is dominated by the need to forecast. When faced with state-of-the-world uncertainty, or even substantial statistical uncertainty,[1] the shorter we can make the planning horizon, the less vulnerable we are to events that defeat specific solutions. However, the length of the planning horizon must be a function of the system's responsiveness and adaptations.

In order to illustrate how these ideas might be applied, and to raise additional issues related to their implementation, we discuss in the paragraphs that follow a specific logistics management problem and a specific policy analytic study we have undertaken in RAND's Resource Management and Systems Acquisition Program. The first example involves the prioritization of depot component repair and allocation of the serviceable assets to bases; the second involves the formulation of a policy study of the Air Force's system for estimating spares and repair requirements.

EXAMPLE 1: PRIORITIZING DEPOT REPAIR AND ALLOCATING ASSETS TO BASES

In AFLC's current component repair workloading system, the worldwide asset position that exists at the end of any particular fiscal quarter is used by the repair requirements computational system to estimate the quarterly repair requirement for the fiscal quarter that begins six months later. Thus, when the repairs actually occur, the data that were used to estimate the requirements for those repairs are six to nine months old. Moreover, the computed repair requirement for any particular quarter may be modified by negotiations be-

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[1]Hodges and Pyles, op. cit. The discussion throughout this section draws heavily from this source.

tween the materiel management and maintenance organizations at the Air Logistics Center. The product of these negotiations is a set of quarterly repair goals to which the depot maintenance activity commits itself, subject to renegotiation during the quarter. The goals are frequently adjusted, most often for lack of repairable carcasses or lack of repair parts. But this reflects nothing more than the uncertainty in the system; reparable generations and demands for repair parts seldom eventuate as forecast. Thus it is seldom sensible to stay tied to negotiated quarterly repair goals when we are trying to achieve specified aircraft availability goals in the face of uncertainty.

Rather than quarterly repair goals, what is needed is a set of estimates of repair demands that may occur during the quarter, along with a measured evaluation of shortages that exist in the system at the start of the quarter, to be used to lay in consumables and allocate depot repair resources. But they should be viewed simply as estimates, not goals. The mix of serviceable assets that actually emerges from the depot as a result of the policies in the current system may be quite different from what would be most responsive to the current needs of the force at the time the repairs are being done.

Given the levels of unpredictability that pervade the system, even in peacetime, the use of such goals seldom makes sense because the asset position evolves so unpredictably. The structure of the process of determining repair requirements implicitly assumes predictability that simply doesn't exist.

The Air Force has the means to implement a much more responsive system of component repair. It operates a supply transaction reporting system called the Air Force Recoverable Asset Management System (AFRAMS). AFRAMS supplies transaction data to a standard AFLC data system designated as D143. Transactions are transmitted daily from base supply computers worldwide into the central system; thus, D143 has the capability to provide a very current snapshot of the worldwide asset position.[2] D143 makes it feasible to prioritize the repair of components using data that are current virtually at the time the repairs are being made. Such an approach helps mitigate the effects of uncertainty in the evolution of the asset position.

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[2] As a practical matter, problems of inaccuracy have been found in the D143 system, apparently due to human errors in data transmission and, perhaps, to other problems. In principle, though, the system is intended to support item managers and others with a very current and accurate view of the worldwide asset position. This discussion assumes that the system operates as intended.

In an attempt to take explicit recognition of uncertainty in repair demands, one might take a somewhat different view of the problem of prioritizing repairs and allocating the serviceable assets to locations worldwide. Consider this problem given the objective of achieving the highest probability of meeting specified aircraft availability goals at the end of a base-specific planning horizon.[3] For those bases that have wartime deployment tasking, we wish to provide spares—in addition to those required to support peacetime flying operations—to carry the unit through the first 30 days of war without depot replenishment. Recall that we pointed out earlier that such a strategy may not be a desirable one simply because of the difficulty in predicting what assets will actually be needed in wartime. The Air Force currently computes its war reserve spares requirements with such a policy. That policy should be reexamined; but if, for the present, we accept that policy as a constraint, we must also accept the consequences of a longer planning horizon and its associated forecasting problems. The length of the planning horizon in this decision problem equals the age of the data, an induction lead time at the depot, an average repair time, and a base-specific order-and-ship time. For those bases with wartime deployment tasking, the planning horizon will be lengthened by an additional 30 days to provide for the spares required for wartime.

This is precisely the planning problem addressed by DRIVE, the algorithm mentioned earlier in this report, a prototype of which was implemented for demonstration purposes at the Ogden Air Logistics Center; it has been used there to demonstrate the feasibility of prioritizing the repair and allocation of F-16 avionics components using asset data from D143.[4] As a practical matter, the peacetime planning horizon used in the DRIVE prototype at Ogden is 18 days plus a base-specific order-and-ship time, plus 30 additional days for bases with wartime deployment tasking. This results in planning horizons between 20 and 50 days long. Thus the DRIVE prototype is undesirably more vulnerable to uncertainty than it would be if lead times were dramatically shorter and if very responsive corrective action could be taken when urgent, unanticipated demands arose.

In determining its asset allocations, DRIVE estimates the expected number of NRTS actions during the total planning horizon for each

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[3]In the simple illustration used here, we assume that the aircraft availability goals are 100 percent at all bases. This implies the need to meet all demands during the planning horizon.

[4]Discussions of this demonstration can be found in Abell et al., and Miller and Abell, op. cit.

base, using peacetime NRTS rates for the peacetime portion of the planning horizon and 100 percent NRTS rates for the wartime planning horizon (because the F-16 deploys without intermediate-level avionics maintenance capability). The expected NRTS actions are then pooled over the entire planning horizon at each base, and DRIVE prioritizes repairs and allocates assets against the pooled expectations using D143 asset data and probability distributions of demands inferred from peacetime demand data.[5]

The robustness of DRIVE's solution to the combat support problem would be enhanced by substantially shortening the planning horizon by making the replenishment system dramatically more responsive. Such an approach would result in specific allocations that would be less vulnerable to uncertainty simply because, when an unanticipated urgent demand arose, the system could respond to it promptly. The need to forecast over long horizons would be mitigated, and the specific allocation solution would be more robust in the face of uncertain futures.

Another part of the original problem that we have not discussed is that of estimating repair requirements. The forecasting problem again raises its ugly head. In order to posture itself adequately by making the proper capital investments, procuring the right mix of skills, provisioning itself with consumables, and planning for future workload, the depot repair activity *must* forecast. Unfortunately, the lead times involved in many of the decisions faced by depot management imply substantial planning horizons. The planning, programming, and budgeting system, for example, requires estimates of resource requirements several years into the future. Thus the need to forecast is often unavoidable. *The lesson to be learned from this research is to couple such forecasts with an execution system that is relevant, timely, and robust, because we know that forecasts wrongly used may commit us to specific solutions that are vulnerable to the future eventuating in ways that our forecasts never suggested.* Our hope is that we will learn to evaluate management alternatives as much in terms of their flexibility and robustness as we do in terms of their attractiveness given our forecasts of the future.

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[5]Formulations of the depot repair prioritization problem and asset allocation problem were considered in earlier RAND research. See Miller, B., *A Real Time METRIC for the Distribution of Serviceable Assets*, RAND, RM-5687-PR, October 1968. See also Buchanan, A. L., et al., *Determining Depot Repair Priorities: Some Informal Notes*, RAND, RM-7904-PR, July 1972.

EXAMPLE 2: A POLICY STUDY OF SPARES AND REPAIR REQUIREMENTS

One important study that emerged from the Uncertainty Project is intended, among other things, to develop an improved approach to estimating spares and depot repair requirements that explicitly recognizes (a) the role of uncertainty in shaping resource demands and (b) management as a resource that shapes system performance.[6] We discuss the study here because it illustrates a practical application in policy analysis of the ideas articulated earlier in this report. Its scope includes primary operating stock (POS, formerly peacetime operating stock) as well as war reserve spares kits (WRSK).

The Air Force's current system for estimating spares and repair requirements models demands for aircraft spare parts as a steady-state process. This leads to serious estimating errors, especially in outyear requirements estimations. Moreover, procurement actions taken in response to changing values of item pipelines over time tend to induce long supply, i.e., an overabundance of assets in the system. The difficulty of estimating outyear requirements correctly is compounded by the long planning horizons involved, often a few years in the case of spares procurement actions, as well as the fact that there is instability in our estimates of item characteristics and our perceptions of what particular kinds of assets will be in the inventory system in the future. The database that supports the Air Force's estimates of spares and repair requirements reflects this instability; it changes substantially from year to year. We call the sum total of all of these changes *churn*. This variability is simply another manifestation of uncertainty. Churn costs the Air Force money because it induces the need for additional investments to maintain a specified level of system performance. Thus two of the principal thrusts of the study are to develop and demonstrate (a) improved approaches to modeling demands and (b) effective strategies to hedge against the effects of churn.

Another important characteristic of the current system is that it ignores the contributions of several management adaptations to system performance in peacetime and wartime. Such adaptations include cannibalization, expedited transportation, priority repair, withdrawals of assets from war reserves during peacetime, and similar

actions taken in response to urgent, unanticipated demands. The third principal thrust of this policy study, the one we will discuss at greater length here, is to develop an improved approach to estimating spares and repair requirements that will (a) account explicitly for realistic levels of statistical and state-of-the-world uncertainty in shaping spares demands, and (b) model the effects of management adaptations on system performance.

The current requirements system makes many assumptions in trying to represent the logistics system and the environment in which it will operate in the future, assumptions of the variety enumerated earlier. Often, these assumptions are clearly inconsistent with behavior in the logistics management system. Most of the assumptions are conservative in the sense that they induce the procurement of more spares than might otherwise be procured. Moreover, the requirements system ignores several management adaptations that act to improve logistics system performance in the face of uncertainty:

- Consolidating asset shortages into the least number of next higher assemblies (cannibalization).
- Priority repair or expedited repair.
- *Expedited transportation and handling.*
- Withdrawals of assets from WRSKs.
- The availability of POS assets for use in wartime deployments.
- Lateral supply.

On the other hand, the system also makes assumptions that are counterconservative. An example is the assumption that the only bases to which stock levels need to be allocated are those that have experienced two or more demands in the previous 12 months. It is impossible to model accurately a system as complex as the Air Force logistics management system. Thus many of its features are not explicitly modeled in the requirements computation, or not modeled realistically. An important task in this study is to determine what management adaptations should be incorporated in the requirements model, how they should be modeled, and to what extent they should shape the determination of requirements.

The design of this study is intended to replicate the Air Force's spares and repair requirements computation (D041), central stock leveling system (D028), and WRSK/BLSS requirements computation and provide the resulting asset position to a capability assessment model, Dyna-METRIC Version 6. Dyna-METRIC will evaluate the peacetime and wartime performance of the stockage posture in terms of the

aircraft availability it delivers. Based on this performance, we will change the assumptions about management adaptations that are made in the current system, and evaluate the new stockage posture that was computed after the changes.

Figure 5.1 illustrates this strategy graphically. Dyna-METRIC Version 6 is a simulation model that incorporates management adaptations and their effects on system performance. Feedback from the evaluations will help us estimate the effects of including specific combinations of management adaptations in the requirements system. Our estimates of system performance coupled with the budgetary implications of alternative models of demand uncertainty and management adaptations will suggest which combination seems to
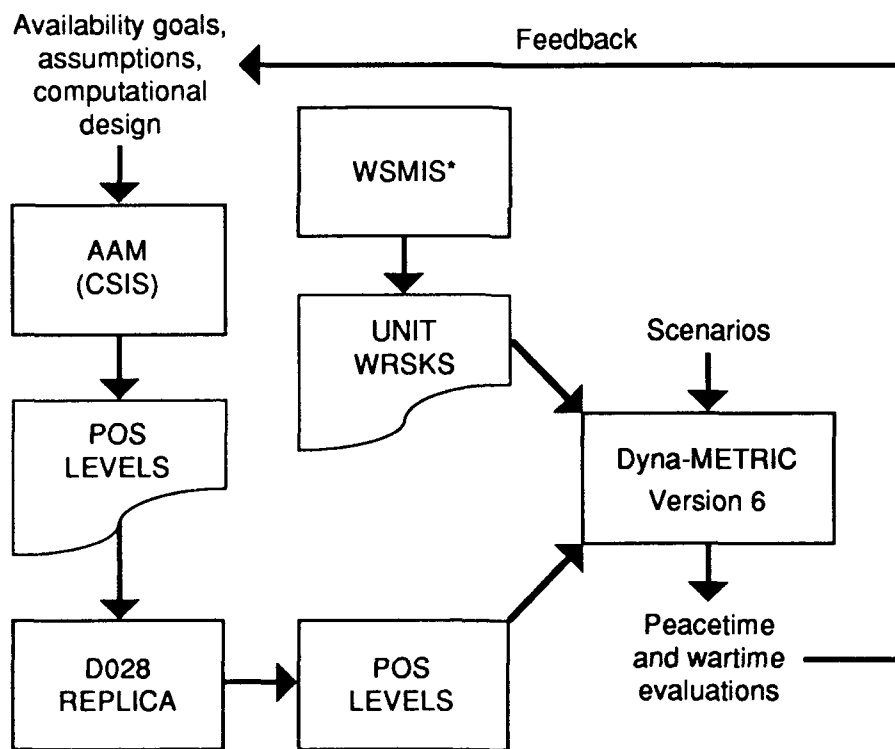
*AFLC's Weapon System Management Information System

Fig. 5.1—Graphic Portrayal of Study Design

yield the least-cost investment mix for an acceptable level of system performance.

But what about uncertainty? In an effort to explicate our uncertainties about peacetime and wartime scenarios, the design specifies the use of several alternative scenarios in the evaluations. Moreover, we will subject the asset position to alternative demand streams even in peacetime. We hope to achieve sufficient richness in scenario variation and demand-stream characteristics so that we will be able to evaluate the robustness of the stockage posture as well as its performance in a specific scenario. For each management adaptation we build into the requirements model, we will specify a scenario that is intended to defeat the payoffs of that adaptation. For example, we will evaluate the stockage posture computed with a cannibalization assumption with a scenario in which the force is dispersed, thus inhibiting the payoff from cannibalization. We will evaluate the stockage posture based on a responsive transportation system with a scenario in which transportation times are lengthened owing to enemy actions and system disruptions. In evaluating the stockage posture in peacetime, we will use demand data from a database three years away from the database used to compute the requirements.

We are hopeful that this approach takes a more realistic view of both uncertainties and management adaptations than does the current system. Its design is an attempt to apply the thinking underlying the CLOUT initiatives to a practical policy study.

6. CONCLUDING REMARKS AND RECOMMENDATIONS

The CLOUT initiatives are examples of management adaptations that enhance the performance of the logistics system in peacetime and wartime. As we have shown, they help mitigate the effects of uncertainties. *To the extent that we ignore the statistical and, especially, state-of-the-world uncertainties in logistics planning, particularly for wartime, we are vulnerable to events unfolding in ways that defeat specific solutions. To the extent that we take explicit and realistic account in planning of our uncertainties and the effects of management adaptations in overcoming them, we will be better able to develop solutions whose performance is robust in the face of uncertain futures.* This is the fundamental message of this work. It is a message that applies to broad categories of management decisionmaking and policy analysis. It is an important message for Air Force logisticians and for those involved in logistics management system design.

The Air Force has already incorporated a set of CLOUT-like initiatives in its new Logistics Concept of Operations. The Major Commands and the Air Staff are thinking through the implementation of such initiatives. In general, the evaluations discussed in this report and the logic underlying the CLOUT initiatives suggest the pursuit of additional research and exploration of management initiatives that will make the logistics system more flexible and responsive in the face of uncertainty. Depot material support policy, depot contract repair policy, material processing and handling during each segment of the depot and base repair pipelines, and exploration of the tradeoffs between investments that shorten item pipelines and investments in aircraft recoverable spare parts are topics that are consistent with the spirit of this work and that seem worthy of investigation by logistics ar.d financial analysts and managers. The payoffs of a responsive logistics system are clear. The problem is how to achieve required levels of performance at reduced costs. That, we feel, should be the central focus of Air Force logistics research in the immediate future.

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