

Improving Naval Aviation Depot Responsiveness

Marygail K. Brauner, Daniel A. Relles,
Lionel A. Galway

RAND

ARROYO CENTER

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PREFACE

In November 1989, RAND presented a series of hypotheses, proposals, and results from exploratory research to a group of senior Naval logisticians at the Naval Postgraduate School, Monterey, California. The general objective of the proposals was to consider whether lessons learned in previous RAND research might apply to the Naval logistics system; the specific goal was to consider how the detrimental effects of uncertainty on mission capability might be offset by management adaptations. RAND's capability assessment models were to be used for much of the research.

This report documents that research. The results are expected to interest Naval maintenance and supply officers, and, because some problems faced by the Naval aviation logistics system are common to all services, it is hoped that they will interest logisticians in the other services as well.

The work described in this report was done as part of the project *Enhancing the Logistics System: The Depot Perspective*, sponsored jointly by the Navy Secretariat, NAVAIR-43, and NAVSUP.

SUMMARY

BACKGROUND

The need for carriers to be self-sufficient when deployed thousands of miles from home base is obvious. However, carriers cannot be entirely self-sufficient, because they operate in an environment of uncertainty. For example, types and intensities of sorties can change depending on operations, causing the need for a different mix of parts than was planned for during predeployment provisioning. Parts that were never a problem can suddenly become *showstoppers* because of environmental conditions, different usage patterns, or a change in quality. The Naval aviation logistics system must function so as to mitigate the effects of such problems. And now, with the likelihood that these problems will be exacerbated by future reductions in the money available to the Naval supply system, it becomes even clearer that the system must be prepared to cope with unexpected problems if the Navy is to adequately maintain aircraft mission capability.

Past RAND research for the Department of Defense evaluated the effectiveness of management adaptations in mitigating some of the effects of uncertainty. The adaptations studied included responsive, prioritized component repair; lateral repair; lateral supply; responsive transportation; and cannibalization. The results of that research led us to believe that the payoff associated with closely tying depot repairs to the day-to-day needs of the fleet would be high.

OBJECTIVE AND SCOPE

Our research involved applying some of the findings of past RAND research to the Naval aviation logistics system. Our overall objective was to determine the consequences of increasing the Navy depot's role in the logistics system by directing its resources toward the day-to-day needs of the fleet. Using a simulation, we asked whether the mission capability achieved with the current aviation logistics system for a 90-day war could be improved through some combination of responsive stocks management, proactive use of depot repair facilities, and shortened transportation pipelines between carriers and depots.

For this initial exploration, we could not consider all types of aircraft found on a carrier or even all components of a single type of airplane. Instead, we examined one system on one airplane—the AWG-9 radar

system on the F-14. We chose the AWG-9 in part because it is largely repaired in a self-contained shop at the depot. We also chose it because it is a mature system, is important to mission capability, and breaks frequently.

APPROACH

To measure the effects of changes in the logistics system, we used data analysis and Version 6 of RAND's Dyna-METRIC model.¹ Dyna-METRIC is a RAND-developed simulation program that allows the user to deploy carriers, fly airplanes with specified intensity, break parts, repair parts at all levels, and count the number of fully mission capable (FMC) aircraft over time. It has been used by both the Air Force and the Army to study the contributions of their aviation logistics systems to readiness and sustainability. Earlier studies at RAND and at the Center for Naval Analyses (CNA) helped us to formulate questions about Naval aviation logistics that Dyna-METRIC is capable of addressing.²

For our research, Dyna-METRIC needed a complete description of the AWG-9 radar system: its parts, the indentured relationships among parts, the performance characteristics of parts (e.g., break rates, variation in break rates over time), stock levels, and repair requirements. To assemble these data, we tapped three information sources: (1) the Navy Maintenance Support Office (NAMSO), (2) the Aviation Supply Office (ASO), and (3) the North Island (San Diego) Naval Aviation Depot. We also built several data files of our own, mostly crosswalk files to link the various data sets together.

To establish a baseline against which to compare changes in the logistics system, we first modeled a scenario that was typical of how the Navy routinely operates carriers. We then ran the simulation for a 90-day war, summarizing the number of FMC radars over the days of the war. The next step was to look at the effect of different management actions (policy changes) to see whether the number of FMC radars could be improved:

- Having the depot fix non-ready-for-issue (non-RFI) stock.

¹Dyna-METRIC Version 5 is documented in Isaacson and Boren, 1988. Version 6 documentation is forthcoming.

²CNA recently used Dyna-METRIC in a study of reliability, maintainability, readiness, and support costs for the F/A-18 engine (Geis, 1990).

- Having the depot repair what was most needed (i.e., perform repair work on a priority basis).
- Placing more or less test equipment at the depot.
- Shortening transportation pipelines.
- Stocking carriers differently.

Finally, we examined the robustness of the simulation results for variations in our logistics system.

RESULTS

We found large variation in mission capability for different input parameters. In some cases, after 90 days of war, certain parameterizations of the transportation and supply systems doubled the number of FMC radars. Specifically, we found that

- Repair of a random sample of the non-RFI AWG-9 stock increases mission capability, but priority repair of only 10 percent of the non-RFI stock produces almost as many FMC radars as fixing all of the non-RFI stock.
- Shortened pipelines (both retrograde and order-and-ship times) improve mission capability by 30 percent or more.
- Replacement of the standard aviation consolidated allowance list (AVCAL), which has many low-demand items, with one that is based on aircraft availability goals has a small but positive effect on mission capability.
- Priority repair combined with shortened transportation pipelines increases the number of FMC radars by anywhere from 33 to 70 percent.

All of these improvements proved to be robust when repair capacity was reduced, a troublesome part was removed from consideration, and demand variability was both increased and decreased.

CONCLUSIONS AND RECOMMENDATIONS

Four basic conclusions emerged from our research—three from the simulation results and one from our experience in collecting the data needed for the simulation. We present them here, along with some recommendations.

Priority Repair at the Depot

Our simulation results show that priority repair at the depot can make an important difference in mission capability. Information systems needed for quick response should be in place prior to any contingency. Then, when surges are required, the depot can focus all of its resources on repair. Specifically, the Navy should consider

- Systematically constructing complete lists of parts for weapons systems.
- Putting in place data systems that support repair prioritization at the depot.

Better Data Systems Integration

The conclusion that emerged from our data analysis activities is that data synthesis is a missing ingredient in the Naval aviation logistics management system. This lack inhibits the depot's ability to react quickly in support of sudden demand peaks.

In this era of reduced defense budgets, the Navy's resources are decreasing and every part is becoming more valuable. It is thus increasingly important for the depot to know where parts are and for ASO to know how parts are functioning in the active squadrons so that the depot can be appropriately tasked. An ongoing capability that links Navy data files is needed for an integrated, responsive logistics management system.

Shortened Transportation Pipelines

Our simulations showed that shortened pipelines can have large effects on mission capability.

The Navy's transportation system provides for constant resupply among the carriers, naval air stations, naval supply centers, and depots. But parts flow through the system very slowly. If the current transportation pipelines are examined to determine where bottlenecks occur, the cost of making the system more efficient can then be estimated. Future wartime planning should place greater emphasis on responsive transportation of stock both to and from the fleet.

AVCAL Selection

We found that constructing an AVCAL based on aircraft availability goals may have some promise for maximizing aircraft availability per dollar spent.

Provisioning carriers for deployments is both expensive and time consuming. It is impossible to mentally manipulate the interrelationships of repair resources, asset availability, and demand rates for thousands of parts while trying to stay within a fixed budget. A decision support system that organizes the necessary information would enable the user to make trade-off decisions. The resources involved in establishing a fully functional decision support system would be enormous, but the Navy could, as an interim solution, begin experimenting now with alternative algorithms for AVCAL selection.

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ACRONYMS AND DEFINITIONS

ASC	activity sequence codes
ASO	Aviation Supply Office
AVCAL	Aviation Consolidated Allowance List
AWG-9	radar system for F-14 aircraft
B08	system for scheduling repairs at naval aviation depots
BCM	beyond the capability of maintenance
BOM	bill of materials
CABAL	Carrier Based Air Logistics
CLOUT	Coupling Logistics to Operations to meet Uncertainties and the Threat
CNA	Center for Naval Analyses
CV	aircraft carrier
DRIVE	Distribution and Repair in a Variable Environment
DRMS	Defense Resource Management Study
DSFBOF	back-order file; completely unfilled requests
DSFINC	back-order file, partially filled requests
Dyna-METRIC	Dynamic Multi-Echelon Technique for Repairable Item Control
FMC	fully mission capable
FOCUS	ASO's data management and retrieval system
I-level	intermediate level
NADEP	naval aviation depot
NAMSO	Naval Maintenance Support Office
NAS	naval air station
NAVAIR	Naval Air Systems Command
NAVFLRS	Naval Flight Records
NAVSUP	Naval Supply Command
NIIN	national item identification number
NSC	naval supply center
PPR	Planned Programmed Requirements
QPA	quantity per application
RFI	ready for issue
RIC	requisitioner identification code
SRA	shop replaceable assembly
TRLRN	ASO's name for FOCUS inventory files
VIDS/MAF	visual information display system/maintenance action form
VTMR	variance-to-mean ratio

xx

WRA	weapon replaceable assembly
WUC	work unit code
3M	Maintenance and Material Management

1. INTRODUCTION

BACKGROUND

Logistics support in the Navy starts with the premise that carriers should be self-sufficient. This attitude descends from hundreds of years of Naval tradition: "Until the advent of telecommunications, a ship 'over the horizon' was a world unto itself, with its captain absolutely responsible for every soul and consequence that fell under his command" (Builder, 1989).

Yet the carrier cannot be self-sufficient at all times, because it is operating in a world of considerable demand variability and hence uncertainty. For example, the flight-deck operating tempo may be faster than what was planned for during predeployment provisioning. Parts may break at unexpectedly high rates. The flying environment may be harsher than anticipated (as was the case in Operation Desert Shield/Storm), thus causing increased breakage of parts previously not a problem. Or there may be unforeseen repair problems because of a batch of bad parts.

In addition, problems associated with uncertainty are likely to be exacerbated by reductions in the money available to the Naval supply system. For example, if lower funding leads to reduced stockage, it will be increasingly difficult to outfit carriers with safety stock and increasingly important to better manage the assets available in the system. That means quickly finding available parts, quickly getting them to the carriers, and repairing the most-needed parts first.

RAND's logistics research has focused on how uncertainty affects demand processes and on the attendant problems of wartime logistics support.¹ One research project sought to understand the etiology of *problem parts*, particularly repair parts (Crawford, 1988). It revealed that problem parts tend to have high demand-rate variability. Another research effort focused on the effectiveness of management adaptations for coping with wartime uncertainty (Cohen, Abell, and Lippiatt, forthcoming). These adaptations—which include responsive, prioritized component repair; lateral repair; lateral supply; responsive transportation; and cannibalization—were shown to mitigate some of the effects of uncertainty.

¹Appendix A summarizes the RAND logistics studies, including those for the Navy, that influenced the research described in this report.

OBJECTIVE

We applied some of the findings described above to the Naval aviation logistics system, looking particularly at the consequences of increasing the naval aviation depot's (NADEP's) usual role in the logistics system by directing its resources toward the day-to-day needs of the fleet. Using a simulation model, we asked whether the mission capability achieved with the current logistics system for a 90-day war could be improved through some combination of responsive stocks management, proactive use of depot repair facilities, and shortened transportation pipelines between carriers and depots.

SCOPE

This effort entailed acquiring an understanding of the Naval aviation logistics system, building data bases that describe the system and how it performs, simulating the system in both its current and alternative states, and analyzing the results of the simulations.

For this initial exploration, we could not consider all of the types of aircraft found on carriers or even all components of a single type of aircraft. Instead, we examined one system on one aircraft—the AWG-9 radar on the F-14.² The scope of our research is thus restricted to fully mission-capable (FMC) radars rather than FMC airplanes.

We chose the AWG-9 radar for our study in part because it is largely repaired in a self-contained shop at the depot.³ We also chose it because it is a mature system, is important to the F-14's mission capability, and breaks frequently.⁴ Table 1.1 shows the repairable AWG-9 WRAs and SRAs in the supply system. As can be seen, the number

²The AWG-9 has more than 460 repairable weapon replaceable assemblies (WRAs) and shop replaceable assemblies (SRAs). When last purchased (1987), it cost \$3,286,558. Developed by Hughes Aircraft Company in the mid 1960s, the AWG-9 is still said to be the most powerful airborne radar in the world today.

³Parts are scheduled for repair at the depot via two different processes: a *level schedule* and the *B08 probe*. The repair of level schedule parts, which are high-demand, high-cost parts, is determined quarterly based on negotiations between the depots, the Aviation Supply Office (ASO) and the fleet. Three of the AWG-9 parts are repaired under level schedule. The B08 probe is a weekly listing of parts needed by the supply system; it has four priority levels. Almost all AWG-9 parts are priority 2, end-use back orders and planned program requirements. The depots induct AWG-9 parts from the B08 probe based on the carcasses available and an estimate of the specific depot's ability to repair the part.

⁴See App. B for a discussion of failure rates for AWG-9 radar parts.

Table 1.1
Repairable AWG-9 WRAs and SRAs in
the Supply System

Condition	Description	Number
A	RFI	7,276
F	Non-RFI	5,217
G	Awaiting parts	95
M	In work	418
Total		13,006

of WRAs and SRAs in working order (A condition) and thus ready for issue (RFI) is only about 25 percent higher than the number of non-functioning WRAs and SRAs.

OUTLINE OF REPORT

Section 2 of this report discusses RAND's aircraft capability assessment model, Dyna-METRIC (including the model and scenario inputs), which we used to generate our results. It also discusses our simulation approach. Section 3 describes the actual results from the Dyna-METRIC simulations; Sec. 4 provides our conclusions and recommendations.

Supplementary material is provided in four appendices. Appendix A discusses the previous RAND logistics research that influenced this study, App. B describes our efforts to understand the extent of uncertainty in AWG-9 demand processes, App. C details our data collection efforts, and App. D describes the parameter inputs accepted by Dyna-METRIC.

2. MISSION CAPABILITY ASSESSMENT METHODS

To examine the consequences of making the NADEP a more active player in the Naval aviation logistics system, we wanted to determine whether weapon system availability could be improved by purposefully varying certain control parameters of the logistics system—depot repair schedules, transportation times to and from depots, and redistribution of stock. The main method we used to make this determination was simulation, supplemented by data analysis of the phenomena we observed through simulation. Our main tool was RAND's Dyna-METRIC (Version 6) simulation program.

Dyna-METRIC uses random draws to explicitly model uncertainty, so different simulations with the same parameter settings can lead to very different results. In this respect, Dyna-METRIC is like the real world. In using Dyna-METRIC for our research, we were essentially mimicking and observing numerous different realizations of the logistics process and attempting to identify the themes and trends that transcend the uncertainty issues.

This section describes the Dyna-METRIC simulation program, including the data requirements, system parameters, input specifications, and general simulation strategy. It then details our simulation approach, including what the baseline scenario was, what the model variations were, and how the robustness of the results was inferred.

THE DYNA-METRIC SIMULATION PROGRAM

Dyna-METRIC depicts the transient behavior of component failure and repair based on characteristics of the system, as described by input data sets. It thus enabled us to model the demand for and repair of WRAs and SRAs at the depots and I-level shops.¹ We used it to simulate the removal of components from weapon systems operating at the different units and to follow the flow of repairables and ser-

¹Maintenance is performed at three levels: on the flight line (organizational, or O-level, maintenance), in the carrier or naval air station (NAS) shops (intermediate, or I-level, maintenance), and at the depots. As the level of maintenance increases, so too does the scope. O-level performs routine aircraft maintenance, identifying, removing, and replacing malfunctioning WRAs. I-level repairs the WRAs, often by replacing circuit cards or other SRAs, and can also repair some SRAs. Depots have the greatest repair capabilities of the three. They repair WRAs and SRAs that are beyond the capability of the I-level.

viceables through a multiechelon repair and distribution system. The output included the number of FMC radar, the parts in non-RFI condition, the flow of parts through the system, and the repair activities of depots and I-level shops.

Data Requirements

Dyna-METRIC needed a complete description of the AWG-9 radar system: its parts, the indentured relationships among parts, the performance characteristics of parts (e.g., break rates, variation in break rates over time), stock levels, and repair resource requirements. To assemble these data, we tapped three information sources:

1. *The Navy Maintenance Support Office (NAMSO)*. NAMSO maintains the Maintenance and Material Management (3M) data, which provide usage information on parts and airplanes.
2. *The Aviation Supply Office (ASO)*. ASO maintains data files on assets, parts configurations, acquisition costs, and repair requirements.
3. The North Island (San Diego) NADEP. North Island provided us with additional information on the AWG-9 system.

We also built several data sets of our own, mostly crosswalk files to link the various data sets together. Table 2.1 summarizes the data sets used.

In assembling these data, we encountered numerous difficulties that we believe inhibit the smooth functioning of the Naval logistics system. Section 4 includes recommendations that flow from these experiences, and App. C describes our data collection activities in detail.

System Parameters

Dyna-METRIC allows the user to specify many system parameters when running simulations. For example, repair could be scheduled on a first-come, first-served basis or on a priority basis in which the part with the highest probability of keeping aircraft on the ground would be repaired next. Moreover, level of repair could be specified as (1) repair on a carrier or at a NAS or depot; (2) repair at a NAS or depot only; or (3) repair at a depot only. When repair was completed at a depot, distribution back to a carrier could be on a priority basis (greatest need) or on a back-order basis (oldest order filled first).

Table 2.1
Data Sets Compiled for the Dyna-METRIC Runs

Source	File	Contents
NAMSO	Naval flight records (NAVFLRS)	Dates and durations of all F-14 flights.
	Visual information display system/maintenance action form (VIDS/MAF) records	Trouble reports on all F-14 flights; chronology of O- and I-level repair for each broken part.
ASO	Stocks at NASs and naval supply centers (NSCs) and on carriers	Number of parts in various conditions at each location.
North Island	AWG-9 information	WRAs and SRAs on AWG-9, indentured relationships, repair times, depot-level test stands, and test-stand reliability.
RAND-compiled	Location identifiers	Information links to cope with different location identifiers.
	National item identification number (NIIN) mappings	Changes in part identifiers over time.
	Squadron locations	Squadron-carrier assignments.
	Supplemental	Additional information on AWG-9: depot-only repair, quantity per application, I-level test stands, test-stand reliability.

Scenarios described later in this section provide some insight into how the model was used to approximate different real-world possibilities.

Simulation Strategy

Dyna-METRIC simulated daily WRA and SRA removals based on the flying program and on demand-rate parameters. Removal distributions were characterized by mean demands and variance-to-mean ratios (VTMRs). When a VTMR is 1, the demand distribution is Poisson; when a VTMR is greater than 1, the demand distribution is negative binomial. A removed WRA or SRA immediately entered the queue at the I-level repair facility. When a test stand was available, the time to repair the part was simulated using a negative exponential distribution. Dyna-METRIC determined the next part to repair based on the scheduling discipline in effect. Under priority

repair, the part selected was the one holding the most airplanes down. Under nonpriority repair, the selection rule was first-come, first-served. If the I-level shop did not have the capacity to repair a part or the queues were too long (in our applications, sometimes four days, sometimes two weeks), the part was sent to the depot for repair. At the depot, the part again entered a queue for repair, repair was scheduled based on the scheduling discipline, and the time to repair was simulated using a negative exponential distribution.

Input Specifications

The input data were grouped into four distinct types:

1. *Parts data*: WRA descriptions, SRA descriptions, indentured relationships, application fractions, mean demand rates,² VTMRs, repair resource availability and assignments, stock levels, and lateral supply parameters.
2. *Descriptions of repair resources*: Information on depots, NASs, and carriers, as well as on the transportation resources connecting carriers or NASs with depots.
3. *Scenario data*: Numbers and types of aircraft at each carrier or NAS, sortie rates, maximum sortie rates, flying hours per sortie, attrition rates, and carrier or NAS damage.
4. *Miscellaneous data*: Carrier, NAS, and depot administrative times, and controls on lateral supply.

Appendix D provides more detail on the input specifications.

SIMULATION APPROACH

To establish a baseline against which to compare changes in the logistics system, we first modeled a scenario that was typical of the way the Navy routinely operates carriers. We then ran the simulation for a 90-day war and summarized the number of FMC radars over the days of the war. We chose 90 days because that is the standard for carrier aviation provisioning.

Our next step was to vary individual system parameters, such as transportation times and stock levels, repeating the simulation and

²We used data from the 3M system on AWG-9 repairs in 1987–1988 at all Navy installations to calculate these demand rates. Currently, we are exploring wartime versus peacetime demands using 3M data from Operation Desert Storm. It should be noted that many Navy officers have said that the Navy practices the same way it fights, with the result that wartime and peacetime demands do not differ.

summarizing the effects of the changes in terms of the number of FMC radars (averaged over all random draws). We examined the effects of changing a single parameter and holding all others constant; we also changed several parameters simultaneously and observed joint effects. Summaries of how mission capability varied with changes in the parameters are provided in Sec. 3.

Baseline Scenario

Our baseline scenario represented our best attempt to portray current Navy practice. It was characterized by the following attributes:

- *Long transportation pipelines (eight weeks).* The pipeline parameter actually covered two different data inputs: the retrograde time, which we defined as the time from when the part was declared not repairable on the carrier to when it arrived at the depot for repair, and the order-and-ship time, which we defined as the time it took for a repaired part to go from the NSC to the carrier needing the part.³
- *Depot as a last resort.* In the current logistics system, the depot is not a day-to-day player in keeping airplanes FMC. Instead, it is the last resort for repair work. Ship maintenance personnel told us that parts sent to the depot were rarely returned to the carrier.
- *Responsive I-level repair.* On a deployed carrier, I-level repair tries to be very responsive to the needs of the flying squadrons. Over 90 percent of the repair actions in our data occurred in the carrier I-level shop. A part is sent to the depot only when the I-level shop cannot perform the needed repair—i.e., when the I-level shop tries to repair the part and fails, when a key test stand on the carrier breaks and remains broken for a long time, or when the I-level shop has a backlog of two or more weeks.
- *90-day horizon.* Because the stated goal of the current Aviation Consolidated Allowance List (AVCAL) configuration is to provide 90 days of wartime sustainability, we ran the simulation for a 90-day war with the standard AVCAL for 24 F-14 airplanes (two squadrons) having FMC AWG-9 radars.

³The one analytical study of transportation time available at the time of our research was by Johnson (1981). It shows that retrograde times average about 65 days, order-and-ship times about 25 days. Our conversations with carrier supply and maintenance officers, however, suggested that eight weeks was the current conservative estimate of these times.

- *Two carriers, one depot.* We believed that a simulation involving two deployed carriers with one depot to support them would closely approximate Navy practice prior to Operation Desert Shield. We wanted to stress the logistics system even in our baseline case, so the simulation was run with 700 flight hours per squadron per month.
- *Standard AVCAL.* AVCALs are negotiated by carrier supply officers and ASO, and vary among deployments. ASO's Planned Programmed Requirements (PPR) file contains a generic AVCAL. Since this generic AVCAL did not differ much from the AVCALs recently used by the USS *Constellation*, USS *Independence*, and USS *Vincent*, we concluded that it was an appropriate standard for simulation and assumed that carriers were fully provisioned with it.
- *Full cannibalization.* Because cannibalization is routinely practiced at all repair levels in the Navy, the fact that the current version of Dyna-METRIC supports only full cannibalization for WRAs did not detract from the model's realism. It did, however, prevent us from experimenting with no-cannibalization scenarios to see how much of a part cannibalization plays.
- *Attrition and lateral resupply.* We assumed no attrition of aircraft and no lateral resupply or repair between carriers.

Model Variations

After establishing the baseline, we sought to model management actions that could adapt to the uncertainty in repair demands so as to improve mission capability. We wanted to evaluate each parameter variation individually (the marginal effect) and then combine variations to achieve an even more effective repair environment. The four individual parameters evaluated were as follows.

Repairing Differing Amounts of Non-RFI Stock. In looking at the data on asset positions, we noted that very few high-demand items were RFI at the NSCs, but that there were large quantities of high-demand stock in the system in non-RFI condition.⁴ We simu-

⁴We were unable to find out why this situation existed. For one of the AWG-9's parts, the transmitter, the explanation was that a key SRA (the gridded traveling wave tube) was not being repaired by the contractor as scheduled. For the other parts, there was no systematic explanation. The reason was sometimes cost, sometimes a contractor that did not deliver as promised. But more often than not, the reason was unknown.

lated the effect of repairing both a randomly selected 25 percent of the non-RFI stock and 100 percent of it.

Prioritizing Repair at the Depot. Previous research at RAND has shown that it is important to prioritize repairs when repair resources are constrained and must serve for more than one kind of repair (Abell et al., forthcoming; Miller and Abell, forthcoming). Repair prioritization is also important when the sequence in which repairs are made is relevant to the production of a WRA or SRA. Moreover, when aircraft availability is one of the measures of improvement, it is also important to prioritize distribution.

We prioritized repair to maximize part availability and to minimize the number of repair hours. This prioritization considered the proposed flying program, the removal rate of WRAs and SRAs, the stock available on the carrier, and the non-RFI stock at the NSC.

Shortening Transportation Pipelines. Transportation pipelines are a key link in the logistics system. Broken parts need to be moved quickly from the carrier to the depot, and repaired parts need to be moved quickly from the NSC to the carrier. Table 2.2 summarizes the different values used in our simulations of the transportation pipelines. What is shown is a simplification of the transportation pipelines: several segments have been combined into the retrograde time, and other segments have been combined into the order-and-ship time. Our discussions with Navy personnel led us to believe that the baseline total time of eight weeks was conservative under ordinary circumstances.

Modifying the AVCAL. A carrier's ultimate AVCAL is a product of negotiations between carrier personnel and ASO. Typically, carrier personnel ask for more parts for an item that has been troublesome in the past and less parts for an item that saw little usage. AVCALs thus are not constant; they depend on demands experienced on recent cruises. A robust AVCAL is the carrier's attempt to hedge against the effects of uncertainty.

Table 2.2
Transportation Pipeline Parameters
(in weeks)

Case	Retrograde Time	Order-and-Ship Time	Total Time
Baseline	6	2	8
Intermediate	2	2	4
Best	2	1	3

The Center for Naval Analyses (CNA) has researched the construction of AVCALs (Evanovich, 1987; Evanovich and Measell, 1986). It produced a readiness-based AVCAL that it compared to the traditional demand-based AVCAL, both in computer-simulated tests and in an actual deployment of the carrier *Enterprise*. CNA found a moderate increase in the number of FMC aircraft with this different provisioning of the carrier. The standard AVCAL that carriers currently use has been modified based on this CNA research.

Our examination of the standard AVCAL showed that it contains many low-demand items. We thus decided to construct a different AVCAL, called an *availability* AVCAL, that was equal in cost to the standard AVCAL but stocked parts based on aircraft-availability goals. This AVCAL has more high-demand items. We simulated the 90-day war when the carrier was stocked with the availability AVCAL and compared the results with those for the baseline case.

Combined Effects. After looking at the effects of varying each individual parameter, we wanted to see how the logistics system would be affected by combining those variations. To do so, we simultaneously simulated the effects of (a) a four-week pipeline and priority depot repair and (b) a three-week pipeline and priority depot repair. We then compared those results with the ones obtained when each individual parameter was varied alone.

Robustness

It is important that simulation results be robust. To ensure that any improvements in the number of FMC radars would hold for changes in the logistics system, we looked at the effects of three specific variations:

Repair Capacity Reduced. The baseline scenario had two carriers with fully functional I-level repair capacity and one depot with fully functional repair capacity. We decreased the repair capacity on the carriers by 50 percent and repeated all the simulations under this condition. We then also reduced the repair capacity at the depot by 50 percent and repeated all the simulations.

Troublesome Part Removed.⁵ Compared to other AWG-9 WRAs and SRAs, the transmitter (NIIN 010734475) had a very high demand

⁵Two recent RAND studies of weapon system reliability and maintainability suggest management strategies for coping with the maintenance of sophisticated avionics in a wartime scenario (see Gebman, Shulman, and Batten, 1988a,b; Gebman, McIver, and Shulman, 1989a,b).

rate and few RFI spares available in the system. When our baseline simulations were run, the transmitter failed more frequently and was responsible for more nonfunctional radars than any other part. Because we did not want our results to be unduly sensitive to the performance of this one part, we omitted the transmitter and its indentured SRAs, reduced the repair capacity by the amount attributable to keeping the transmitter functioning, and reran the simulations.

Variability in Demand Rates. The inability to forecast demands is partially characterized by the high variance of observed demand rates over time. The demand-rate VTMR is a standard measure of such variability: the higher the VTMR, the greater the unpredictability.⁶ We estimated VTMRs from demand data in the 3M files (see App. B) and found them to be generally between 1 and 2. The baseline scenario was run with a VTMR of 3. To test for robustness, we also examined the effects for VTMRs of 1 and 5.

⁶For a discussion of the formulas used to calculate VTMRs and the general problems involved in modeling demands for spare parts, see Hodges (1985).

3. SIMULATION RESULTS

Plots of the number of FMC radars by days of the war proved to be an effective way to study the impact of parameter changes on the simulated Naval aviation logistics system. This section presents those plots.

We start with the baseline simulation results, which are our projection of what would happen in a 90-day war given the baseline conditions described in Sec. 2, i.e.,

- Long transportation pipelines (eight weeks)
- Depot as a last resort
- Responsive I-level repair
- 90-day horizon
- Two carriers, one depot
- Standard AVCAL
- Full cannibalization
- VTMR of 3

We then examine the marginal effects of changing one parameter at a time and the combined effects of changing two parameters at a time. Finally, we look at the robustness of these results.¹

BASELINE CASE

Figure 3.1 shows 20 FMC AWG-9 radars (the target number of radars) at day 10, and 11 radars at day 90 for the baseline case. This result is the one we wanted to improve by reallocating resources.

MARGINAL EFFECTS: CHANGING ONE PARAMETER AT A TIME

As described in Sec. 2, we first varied four individual parameters. The results were as follows.

¹All plots depict numbers of FMC radars averaged over 25 replications of a 90-day war. We believe that the averages do not contain much stochastic variation: the patterns were stable for different random number sequences and the same for both carriers. We did not attempt to summarize variability for the separate replications.

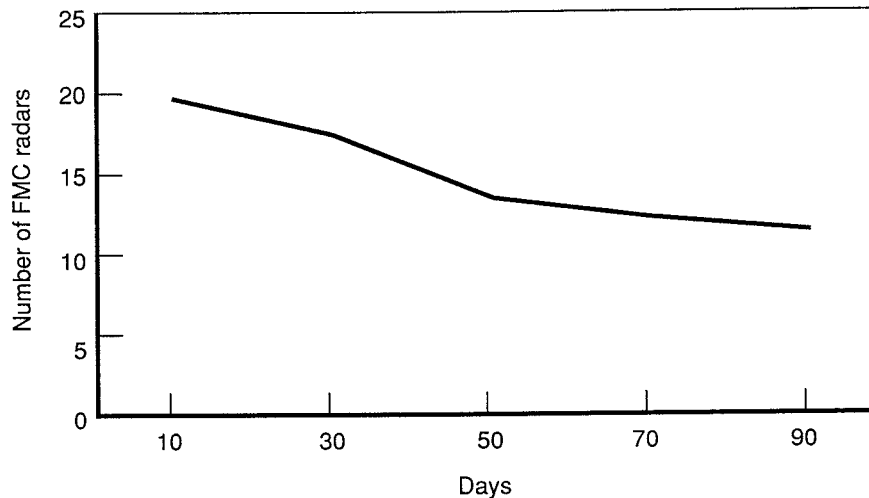


Fig. 3.1—Results for Baseline Case

Repairing Differing Amounts of Non-RFI Stock

As we began to experiment with Dyna-METRIC, we noticed that very little high-demand stock was RFI and yet much high-demand stock existed in the system in non-RFI condition. Figures 3.2 and 3.3 illustrate these findings.

As can be seen in Fig. 3.2, a large number of RFI parts in the system had low numbers (0 to 300) of I-level actions. One of these parts (the one indicated by the highest dot on the graph) had no I-level actions in our data, and yet there were 64 of these items on the shelves at the NSC in RFI condition. In contrast, there was no RFI stock at the NSC for any of the parts with high numbers (2000+) of I-level actions.

Figure 3.3 shows how much non-RFI stock existed. All the parts with 2000 or more I-level actions had 20 or more carcasses awaiting repair. One of these parts (the one indicated by the rightmost dot on the graph) was the AWG-9 transmitter (NIIN 010734475), which had 4410 I-level actions. Our records of the supply system showed 25 of these items in non-RFI condition and none in RFI condition at the NSCs.

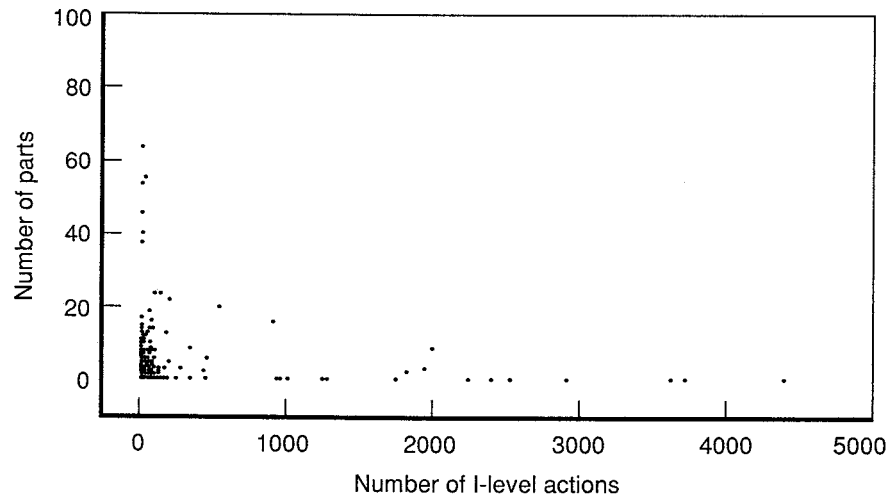


Fig. 3.2—Very Little High-Demand RFI Stock Is Available

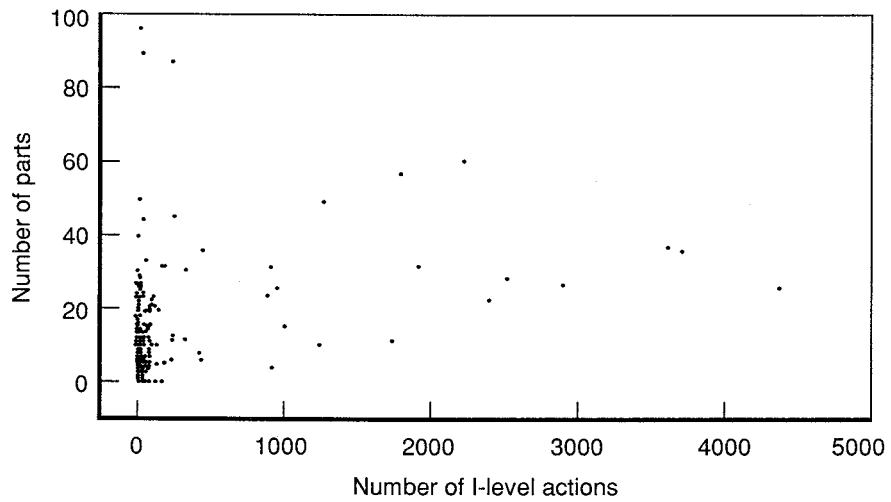


Fig. 3.3—Large Quantities of Non-RFI Stock Exist

We ran the simulation to see how many FMC radars we could produce by fixing the non-RFI stock. Figure 3.4 shows the improvements in mission capability when 25 percent (randomly chosen) and 100 percent of the non-RFI stock were repaired. Note that the 25 percent repair increased the number of working radars by 3 at day 90, whereas repairing the remaining 75 percent added only 1 additional radar. The relationship between FMC radars and stock is clearly not linear. We speculate that the first 25 percent produced a larger number of RFI radars than did the remaining 75 percent because the system needs at least a few spare parts in order for maintenance facilities to keep up with demands. The first 25 percent provided the initial few. Repairing the remaining 75 percent of the non-RFI stock filled a few more demands but mainly put stock on the shelf.

Prioritizing Repair at the Depot

Figure 3.3 shows large quantities of non-RFI stock for parts that had few I-level actions. We assumed that fixing this stock would have little effect on mission capability, but that fixing parts having 2000+ I-level actions would probably increase mission capability substantially.

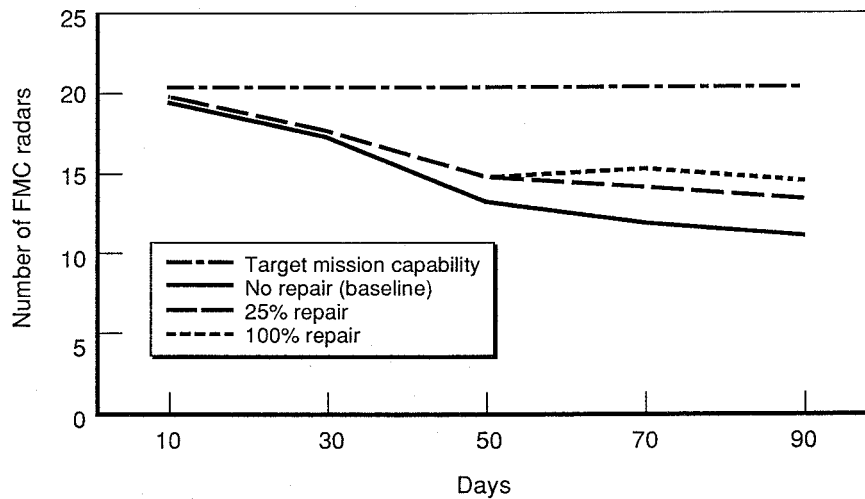


Fig. 3.4—Repairing Non-RFI Stock Improves Mission Capability

We built a prioritized list that attempted to maximize mission capability while accounting for repair resources, break rates, and available stock.² Figure 3.5 reveals the simulated results we obtained when the stock to be repaired was prioritized. With prioritized repair, fixing only 10 percent of the non-RFI stock yielded 80 percent of the gain in number of FMC radars. A comparison of Fig. 3.5 with Fig. 3.4 shows that more mission capability is obtained by repairing 10 percent of the most needed parts than by repairing 25 percent of all parts.

Shortening Transportation Pipelines

Broken parts need to move quickly from the carrier to the depot, and repaired parts need to move quickly from the NSC to the carrier.

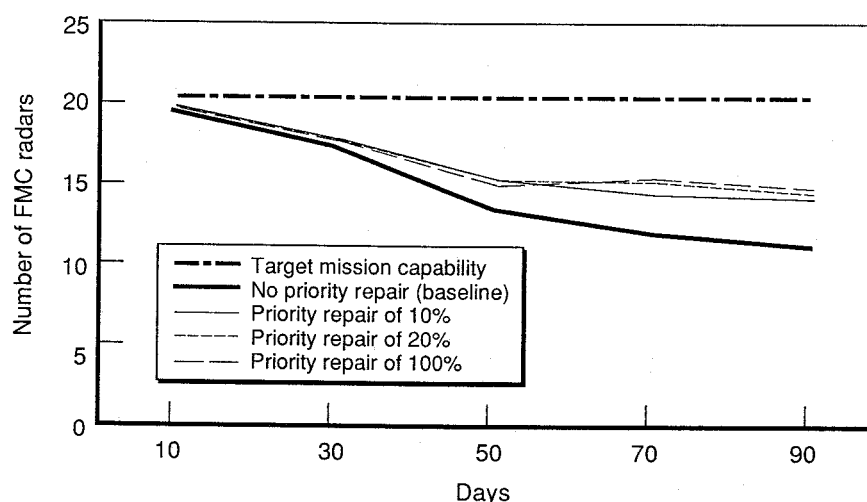


Fig. 3.5—Priority Repair of Non-RFI Stock Improves Mission Capability, with Repair of 10 Percent Yielding Almost All of the Gain

²We used the DRIVE (Distribution and Repair In Variable Environments) model to build the prioritized list of parts to be repaired at the depot. DRIVE is a linear program that maximizes the probability of meeting all the availability goals while accounting for repair costs. Inputs to DRIVE are the number of airplanes, sorties, and flying hours on a carrier; aircraft availability goals for that carrier (e.g., 85 percent of airplanes FMC); worldwide asset position; planning horizon (90 days); repair costs; demand rates for parts on the carrier; beyond-the-capability-of-maintenance (BCM) rates; and failure rates at the depot. See Abell et al. (forthcoming) and Miller and Abell (forthcoming).

Dyna-METRIC allows these times to vary. Figure 3.6 shows the simulation's estimate of the improvements gained by halving the pipelines from eight to four weeks: an increase of 4 FMC radars by day 90 of the war. Decreasing the pipeline further, to three weeks, supplied an additional 1.5 FMC radars by day 90.

Modifying the AVCAL

Figure 3.7 plots the number of parts in the AVCAL versus the number of I-level actions in our data. As can be seen, the AWG-9 tape transport unit (NIIN 010939888) had 163 I-level actions, and the standard AVCAL stocks nine of these parts. Compare this situation to that for the AWG-9 power supply (NIIN 001217359). It had 1929 I-level actions, and the standard AVCAL stocks only four.

We constructed an *availability* AVCAL that was of equal cost to the standard AVCAL but that used DRIVE to maximize radar availability through knowledge of demand rates, repair facilities, and repair times. This AVCAL has more high-demand parts. Figure 3.8 plots the number of parts in the availability AVCAL versus demand rates and shows the same two parts that were marked in Fig. 3.7. Now, however, the AVCAL stocks two of the low-demand tape transport units and seven of the high-demand power supplies.

Figure 3.9 compares our estimates of the number of FMC radars using the standard AVCAL and the availability AVCAL. At day 10 of war, the availability AVCAL increased the number of FMC radars by 0.5. At day 30, the increase was approximately 1.0; and from day 50 through day 90, the increase was about 1.5. These are small gains. Modifying the AVCAL appears to yield only modest improvements, a finding that is consistent with the CNA findings on readiness-based sparing AVCALs (Evanovich and Measell, 1986; Evanovich et al., 1987).³

COMBINED EFFECTS: CHANGING TWO PARAMETERS AT A TIME

When two of the simulation parameters are changed instead of just one—such as repairing stock at the depot on a priority rather than a first-come, first-served basis and also shortening the transportation

³The CNA reports document small increases in the number of FMC F-14As when a readiness-based sparing AVCAL is used rather than a demand-based AVCAL.

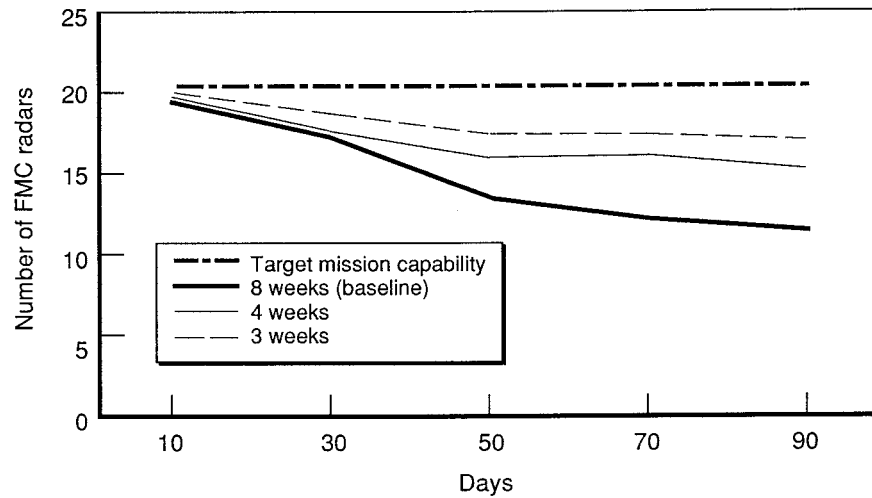


Fig. 3.6—Shortened Pipelines Improve Mission Capability

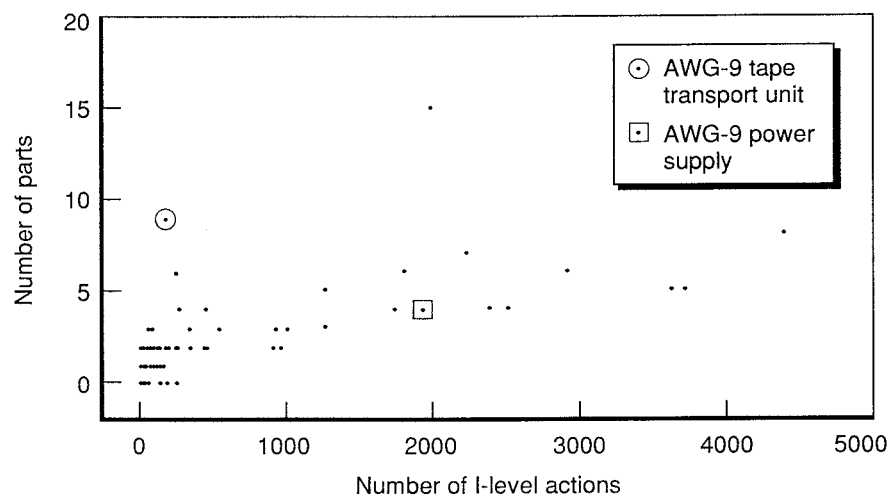


Fig. 3.7—Standard AVCAL Has Many Low-Demand Items

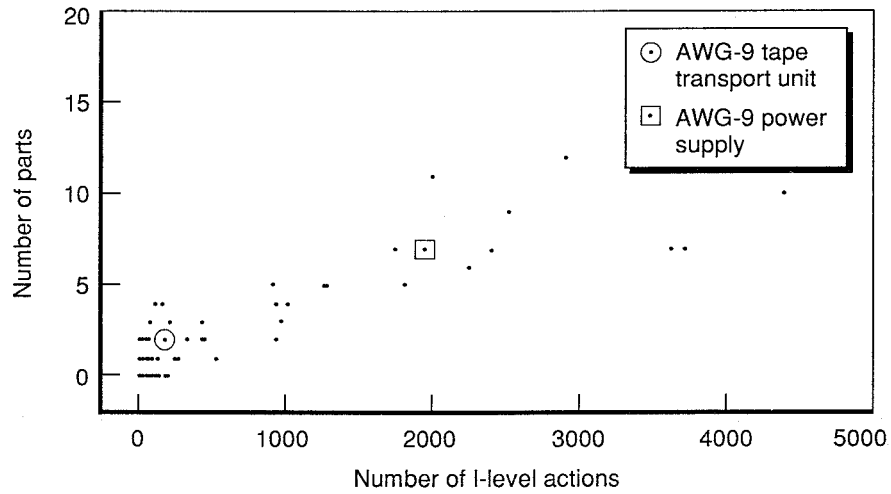


Fig. 3.8—Availability AVCAL Has More High-Demand Items

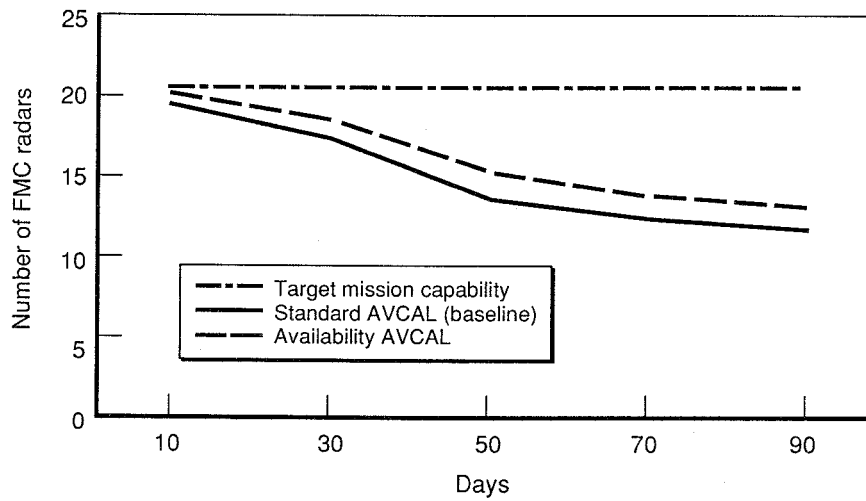


Fig. 3.9—Availability AVCAL Yields Modest Gains in Mission Capability

pipeline—the beneficial effects can be greater than for a single change.

Prioritized Repair with Four-Week Pipelines

We ran the simulation with various fractions of prioritized repair combined with four-week pipelines (two weeks retrograde time and two weeks order-and-ship time). As Fig. 3.10 shows, the number of FMC radars increased by 6 at day 90 regardless of whether 10 or 100 percent of the non-RFI stock was repaired on the basis of priority. This result indicates that getting the right stock into a rapidly circulating system dramatically reduces the need for spare stock.

Prioritized Repair with Three-Week Pipelines

Prioritized depot repair of non-RFI stock combined with three-week pipelines yielded the most dramatic improvements in mission capability. As seen in Fig. 3.11, the target of 20 FMC AWG-9 radars was almost met during the entire 90-day war when repair of 10 percent of the non-RFI stock was prioritized and the pipeline was shortened to three weeks (two weeks retrograde time and one week order-and-ship time).

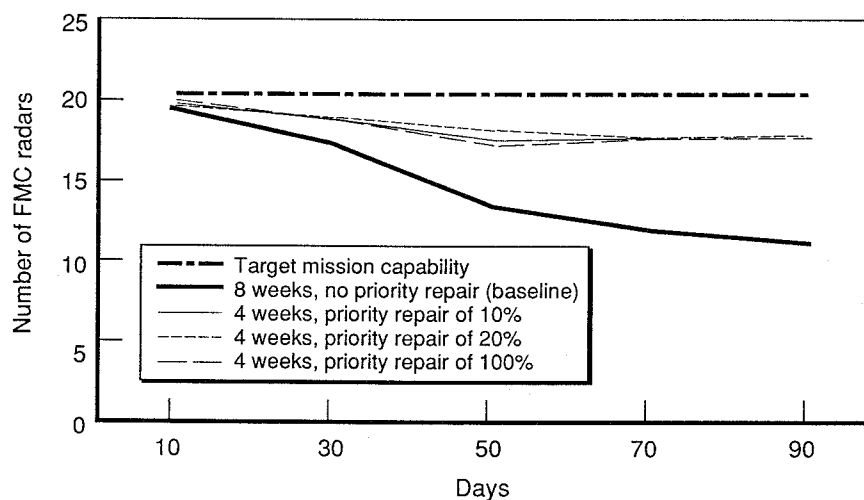


Fig. 3.10—Priority Repair Plus Pipelines Shortened to Four Weeks Significantly Improves Mission Capability

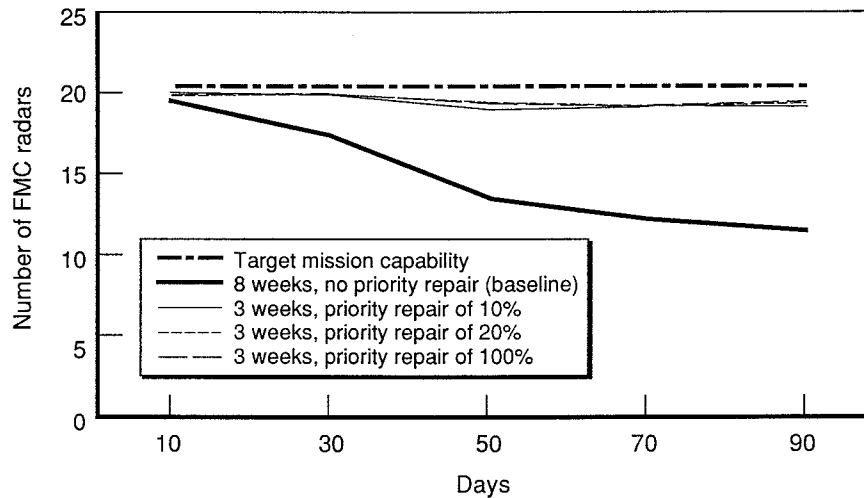


Fig. 3.11—Priority Repair Plus Pipelines Shortened to Three Weeks Yields the Most Improvement in Mission Capability

ROBUSTNESS OF RESULTS

The next series of figures combines two and three plots on the same chart, separated into panels. The vertical axis remains the number of FMC radars, and the horizontal axis identifies for each panel the day of the war. This sequence of simulation results seeks to verify that the improvements in mission capability hold for changes in the logistics system.

Repair Capacity Reduced

Figure 3.12 contains three panels, the first of which shows the results for our original baseline case (Fig. 3.1). The second shows the results for that case when repair capacity on the carriers is cut by one-half; the third shows the results when repair capacity on the carriers and at the depot is cut by one-half. By day 30, the reduced repair capacity has led to 5 less (from 16.5 to 11.5) FMC radars. From day 30 to day 90, the simulations for the reduced repair capacity show a drop to approximately 7 FMC radars. The degradation in the ability to

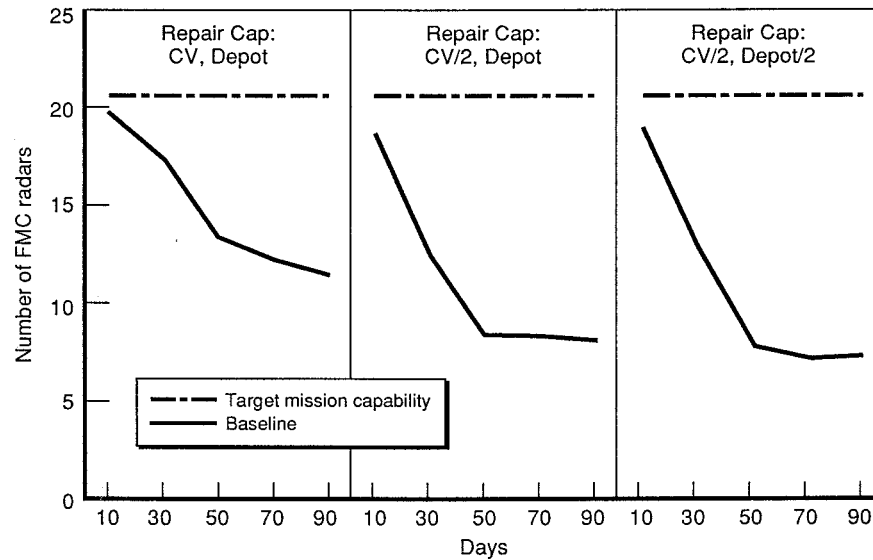


Fig. 3.12—Results for Baseline Case with Reduced Repair Capacity

sustain operations flattens out because the sorties cannot all be flown with so few FMC radars, but those that can be flown can be supported in the reduced repair environment.

Figure 3.13 illustrates the effects of priority repair of non-RFI stock in a reduced repair environment. The first panel is the same plot shown in Fig. 3.5; it shows what happens for different percentages of priority repair. The second and third panels show that reduced repair on the carriers alone and on the carriers and depot combined degrades mission capability and sustained operations. The most important information here, however, is that even with reduced repair capacity, the depot's contribution still improves mission capability. The second panel's improvement over the baseline case is about 4 radars from day 50 to day 90, whereas this improvement decreases to only 2 radars by day 90 in panel 3. When carrier and depot repair capacity are both reduced, the capability for sustained operations is severely diminished.

Figure 3.14 shows that with reduced repair capacity, shortened pipelines still provide improvements in mission capability. Again,

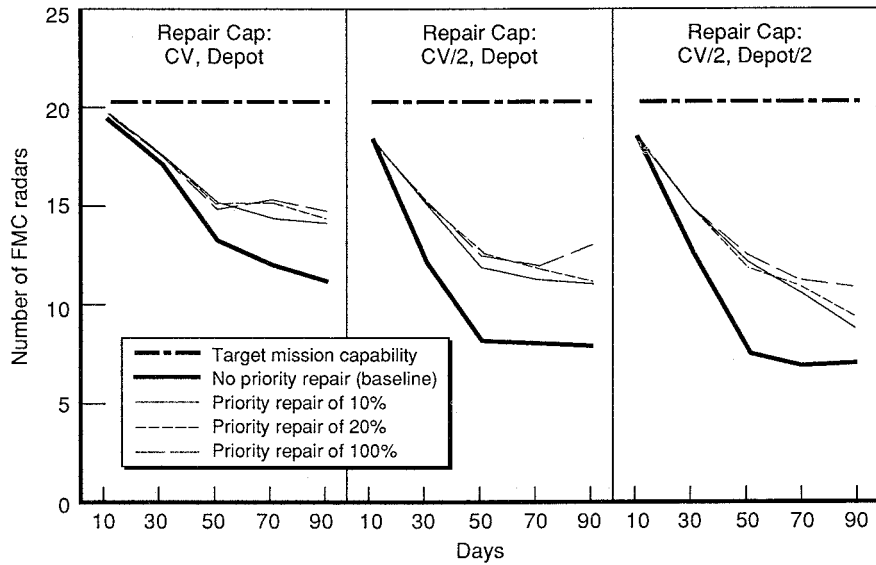


Fig. 3.13—With Reduced Repair Capacity, Priority Repair of Non-RFI Stock Still Improves Mission Capability, with Depot Repair Making a Difference

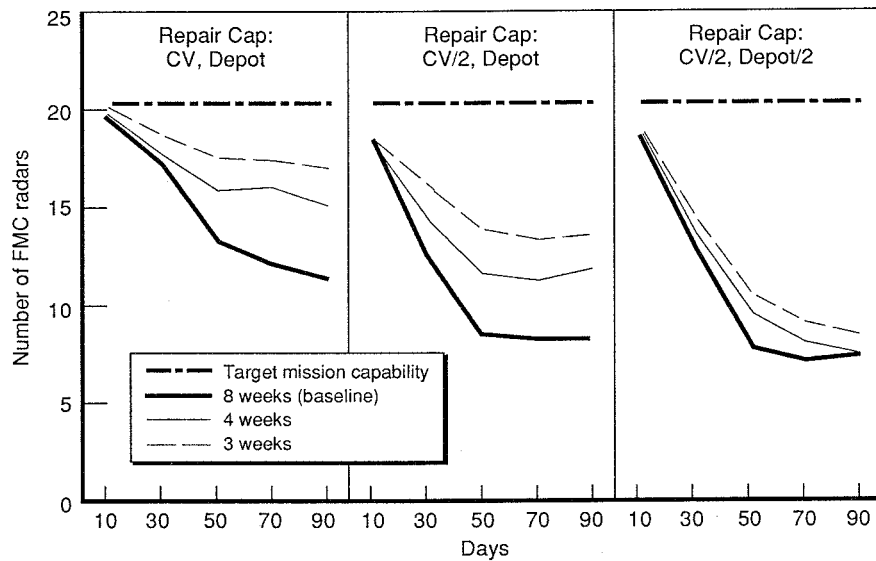


Fig. 3.14—With Reduced Repair Capacity, Shortened Pipelines Still Improve Mission Capability, with Depot Repair Making a Difference

however, the salient point here is that the depot is important. The first panel repeats Fig. 3.6. The second panel shows that for a three-week pipeline (order-and-ship time of one week), a fully-functional depot narrows the gap between the day-90 baseline and target number of FMC radars (7.5 and 20, respectively) by almost one-half. The third panel shows that shortened pipelines can make very little difference in the number of FMC radars when all repair capacity is reduced.

Figure 3.15's first panel duplicates Fig. 3.9, showing the improvement realized by using the availability AVCAL rather than the standard AVCAL for full-capacity repair. The other two panels show that this improvement remains about the same at each day of the war for the two forms of reduced repair capacity.

Figures 3.16 and 3.17 show the reduced-capacity results for the combined parameter changes (the first panels in the two figures duplicate, respectively, Figs. 3.10 and 3.11). With priority repair and shortened pipelines, a fully functional depot (center panels) significantly improves mission capability. However, even when depot

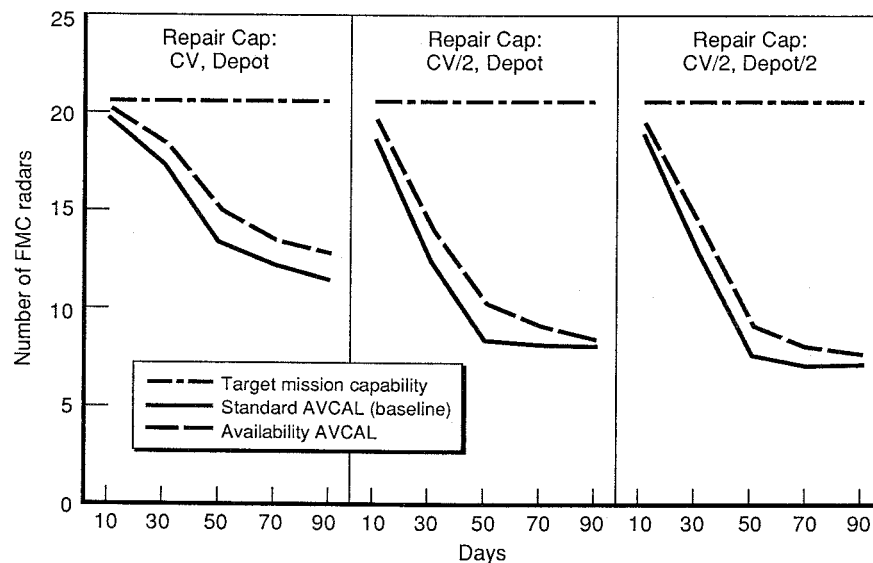


Fig. 3.15—With Reduced Repair Capacity, Availability AVCAL Still Yields Modest Gains in Mission Capability

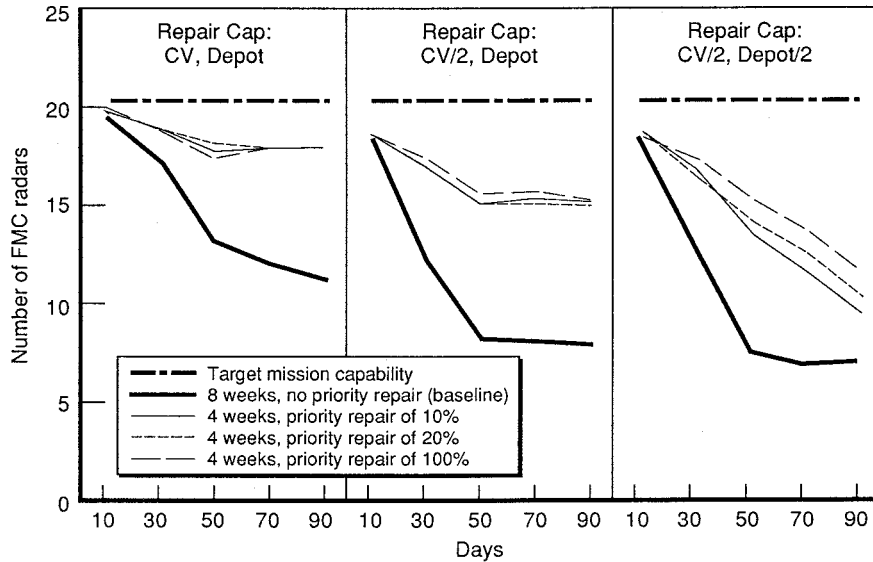


Fig. 3.16—With Reduced Repair Capacity, Priority Repair Plus Pipelines Shortened to Four Weeks Still Improves Mission Capability

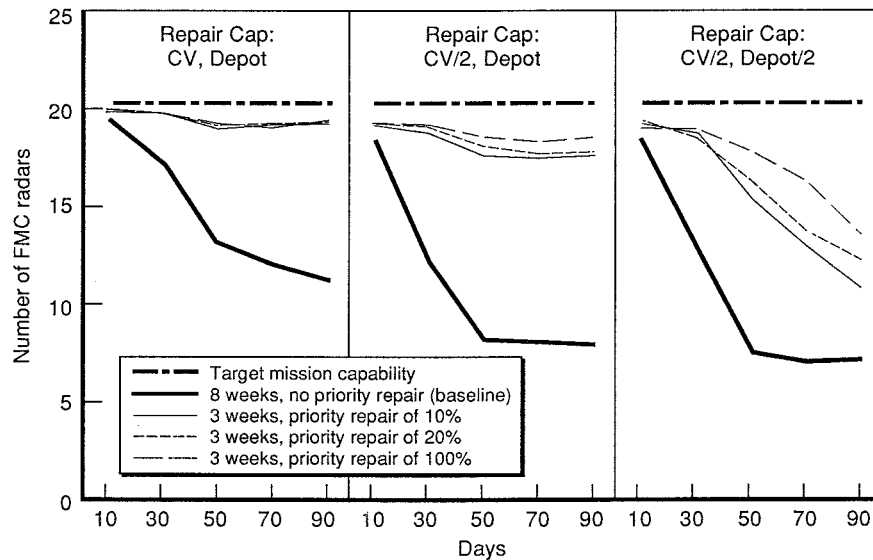


Fig. 3.17—With Reduced Repair Capacity, Priority Repair Plus Pipelines Shortened to Three Weeks Still Yields the Most Improvement in Mission Capability

repair capacity is also reduced (third panels), the number of FMC radars can be increased.

Troublesome Part Removed and Reduced Repair Capacity

We mentioned earlier, in Sec. 2, that transmitter failure was found to be responsible for most nonfunctioning AWG-9 radars. We now demonstrate that our results were not driven by that one troublesome part. The next six figures illustrate the simulation results with the transmitter and its indentured SRAs removed from the data base. These results are essentially the same as the previous ones.

The next six figures each consist of two panels. The first panel shows the results when the carriers and the depot both have their repair capacity reduced by one-fourth, which is approximately the fractional amount of the I-level's time spent on the transmitter in our simulations. The second panel shows the results when the carriers and the depot both have their repair capacity reduced by one-half.

The top line in both panels of Fig. 3.18 shows the target mission capability, 20 FMC AWG-9 radars. The bottom line is the reduced-capacity result for the baseline scenario with the transmitter and its indentured parts removed. It is clear from the second panel that reducing repair capacity degrades mission capability.

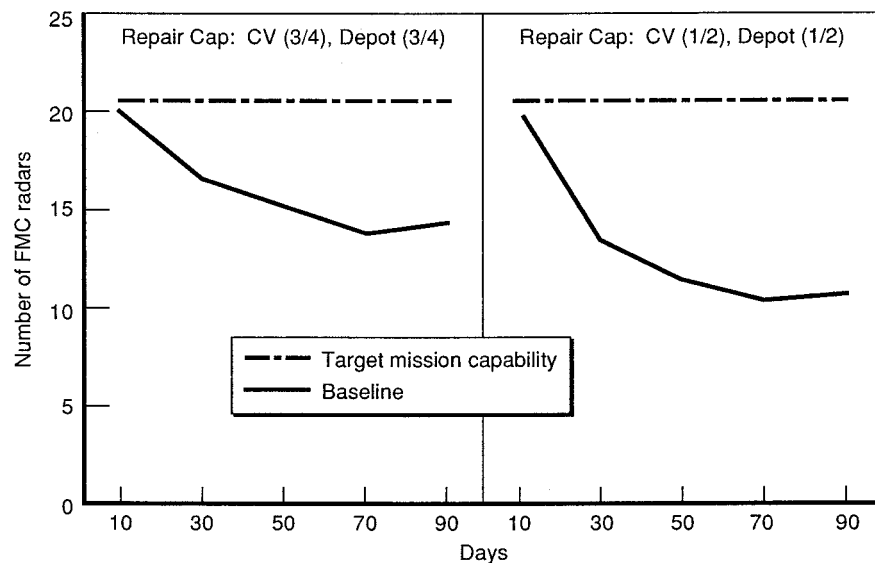


Fig. 3.18—Results for Baseline Case with Transmitter Removed

Figure 3.19 shows that with the transmitter removed from the data set, priority depot repair of non-RFI stock still increases the number of FMC radars. Moreover, Fig. 3.19 shows what was seen in the previous priority-repair figures: repairing 10 percent of the non-RFI stock yields almost all the improvement possible for this variation.

Figure 3.20 shows the shortened-pipeline results with the transmitter removed. As can be seen, for the remaining AWG-9 radar parts and diminished repair capacity, a shortened pipeline still increases the number of FMC radars at each day of the war.

Eight parts are associated with the transmitter in the standard AVCAL, ten in the availability AVCAL. Figure 3.21 shows that when these parts are removed and the simulations run for the remaining parts, use of the availability AVCAL can still modestly improve the number of FMC radars at each day of the war.

Figures 3.22 and 3.23 show the combined effects of priority repair at the depot and shortened pipelines for the remaining AWG-9 parts. The gain in mission capability is much the same as it was when all parts were considered.

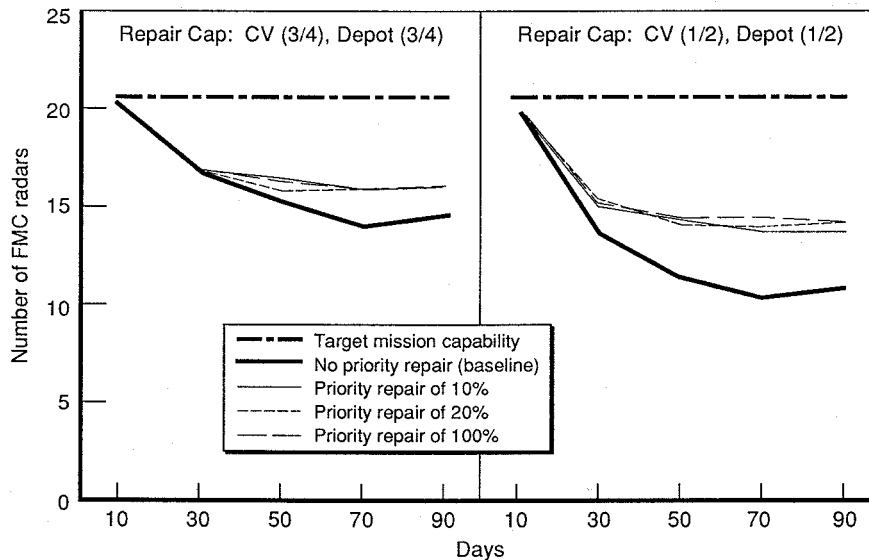


Fig. 3.19—With Transmitter Removed, Priority Repair of Non-RFI Stock Still Improves Mission Capability, with Repair of 10 Percent Yielding Almost All of the Gain

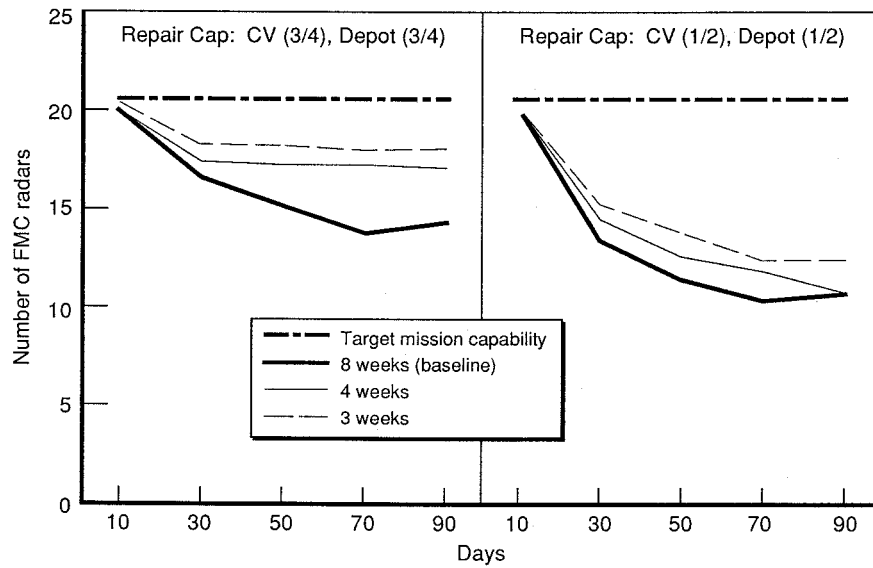


Fig. 3.20—With Transmitter Removed, Shortened Pipelines Still Improve Mission Capability

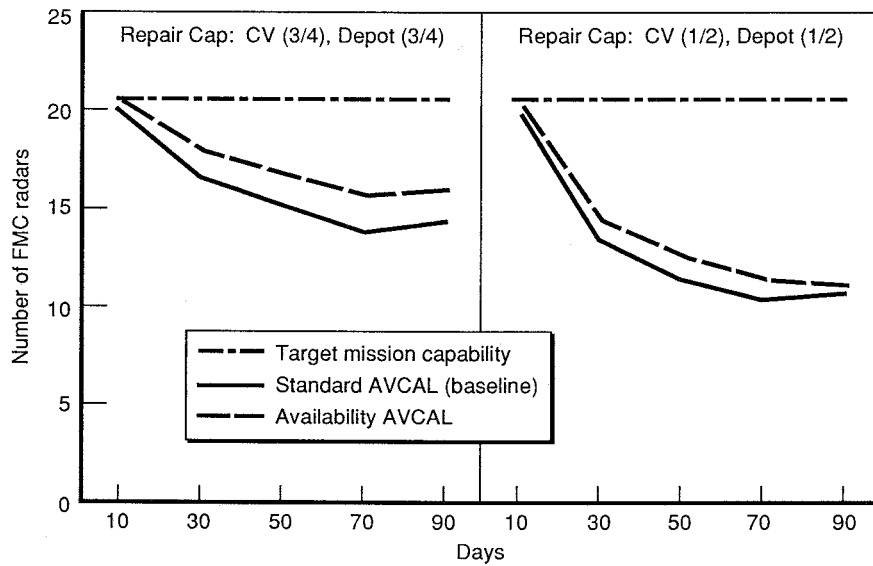


Fig. 3.21—With Transmitter Removed, Availability AVCAL Still Yields Modest Gains in Mission Capability

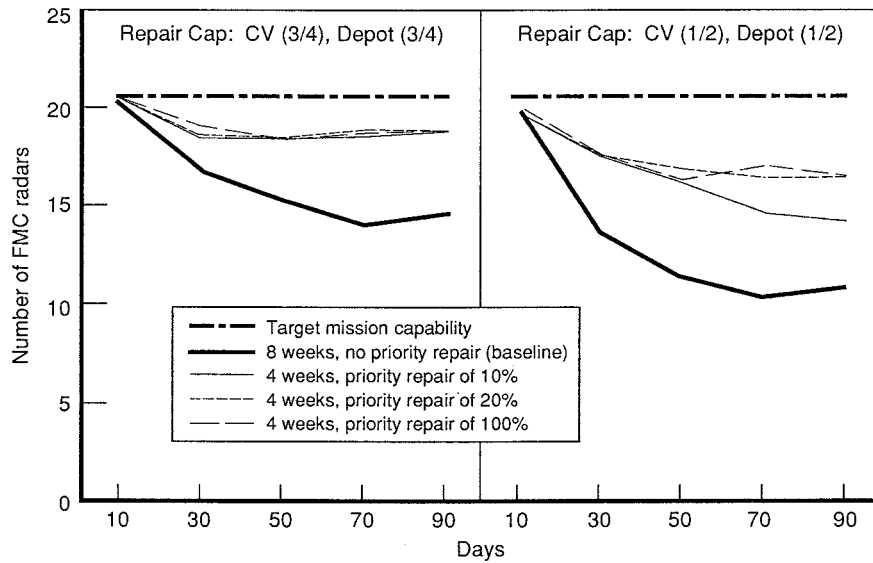


Fig. 3.22—With Transmitter Removed, Priority Repair Plus Pipelines Shortened to Four Weeks Still Improves Mission Capability

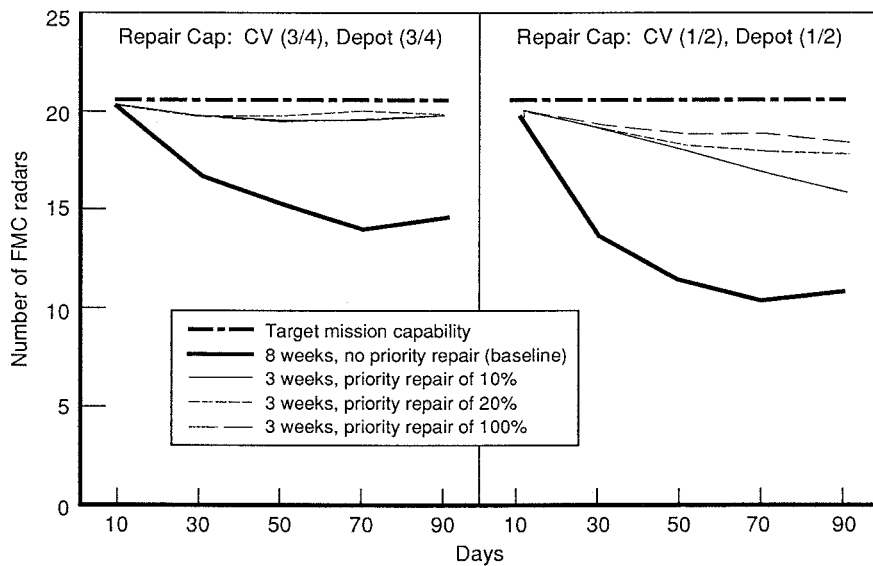


Fig. 3.23—With Transmitter Removed, Priority Repair Plus Pipelines Shortened to Three Weeks Still Yields the Most Improvement in Mission Capability

Using Different VTMRs

The results reported above were based on the assumption that the AWG-9 WRAs and SRAs had a demand distribution with a VTMR of 3, which is a very unstable and unpredictable variation in demand rate (see discussion in App. B). We thus wanted to test our different adaptations of the logistics system with other VTMR values.

We ran the simulations using the assumption that all parts had a demand distribution with a VTMR = 1 (the Poisson distribution), the most commonly assumed demand distribution for failures. We also ran them using a demand distribution with a VTMR = 5. The results are shown and compared to the earlier results for a VTMR of 3 in the next five figures.

Figure 3.24 shows the baseline case for the three VTMRs. As can be seen, compared to the VTMR = 3 case (shown earlier in Fig. 3.1), the VTMR = 1 case has 1.5 more FMC radars on day 50 and the VTMR = 5 case has 1.5 fewer FMC radars. The message here is that, regardless of the variation in demand, the carrier will be very short of FMC radars long before the 90-day planning horizon has passed.

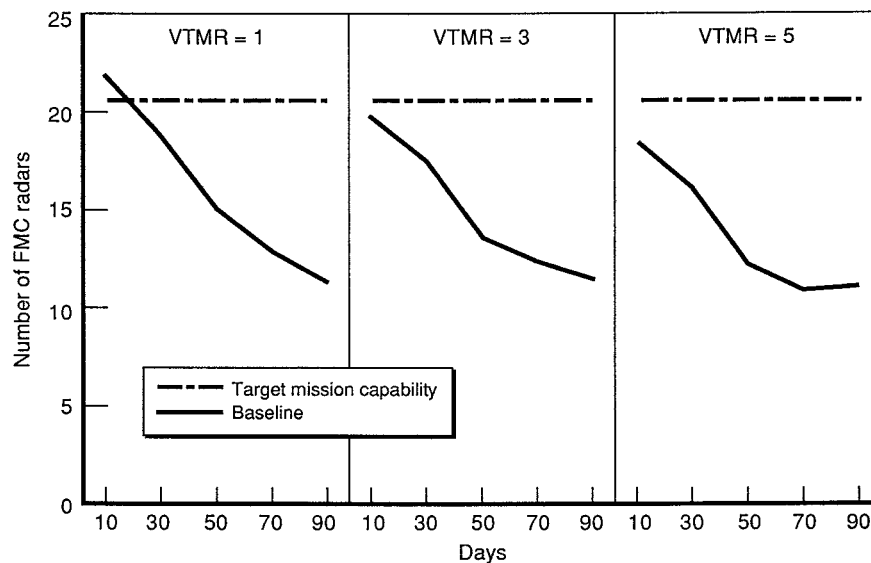


Fig. 3.24—Results for Baseline Case with Different VTMRs

Figure 3.25 shows that the effect of prioritizing depot repair of non-RFI stock is dramatic when the VTMR is low (panel 1), but it is also significant when the VTMR is high (panel 3). The simulation results, consistent across the three panels, show a large increase in the number of FMC radars when the depot can repair the non-RFI stock needed by the carriers.

Figure 3.26 shows the VTMR effects for the shortened pipeline. As can be seen, as the war progresses, getting the non-RFI stock to the depot and the repaired stock to the carrier more quickly increases the number of FMC radars regardless of the VTMR.

Estimates of the number of FMC radars with the standard AVCAL and the availability AVCAL for the three VTMRs are shown in Fig. 3.27. Notice that when demand rate is less variable (VTMR = 1 rather than 3), the availability AVCAL produces 1.3 more FMC radars from day 30 to day 90. When it is more variable (VTMR = 5), the increase is between 0.5 and 1.0. Our purpose in running the simulations with different VTMRs was to verify results across the differing parameters. Figure 3.27 clearly shows consistent results for the three different values of the VTMR.

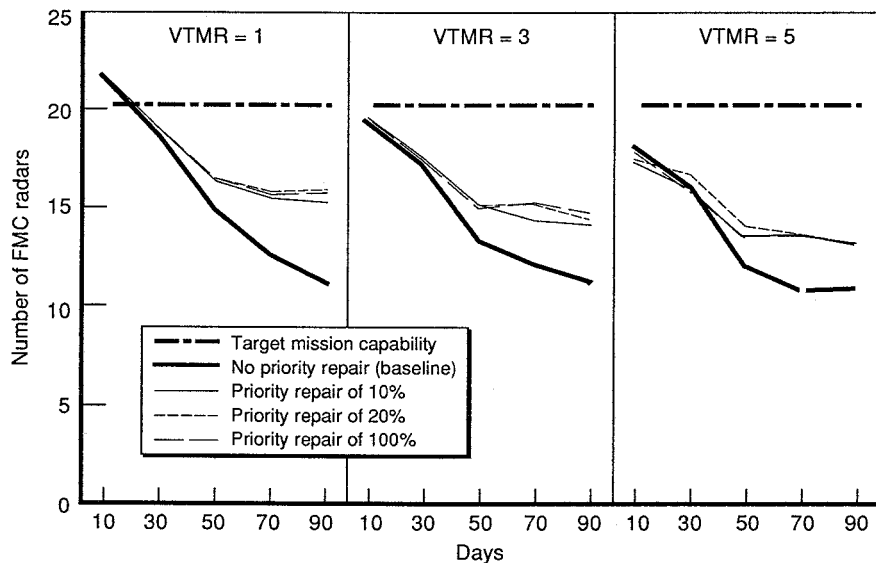


Fig. 3.25—Effects of Priority Repair on Mission Capability Are Large Regardless of VTMR

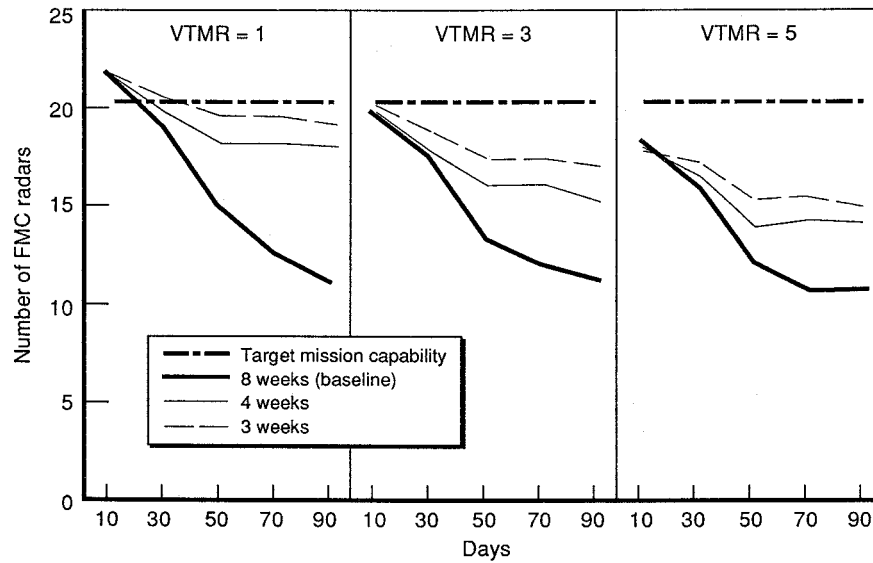


Fig. 3.26—Shortened Pipelines Improve Mission Capability Regardless of VTMR

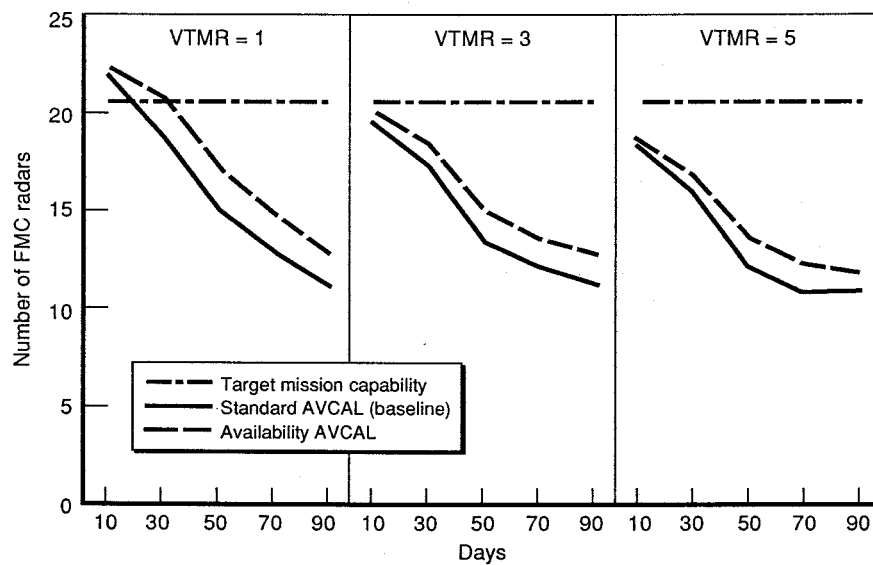


Fig. 3.27—Availability AVCAL Has Marginal Effect on Mission Capability Regardless of VTMR

As we noted in discussing Fig. 3.10, prioritized depot repair combined with shortened pipelines substantially increases the number of FMC radars on each day of the war. As Fig. 3.28 shows, this result holds when the VTMRs are both higher and lower than the VTMR = 3 used in the earlier figure. With VTMR = 1, the target of 20 functional radars is nearly met each day. With VTMR = 5, the plot is similar to that of the center panel but offset by one less FMC radar. The message is the same in all three panels.

SUMMARY OF RESULTS

Tables 3.1 and 3.2 summarize the simulation and robustness results, respectively. What they show for different input parameters is that

- Repair of a random sample of the non-RFI AWG-9 stock increases the number of FMC radars, but priority repair of 10 percent of the non-RFI stock produces almost as many FMC radars as fixing all of the non-RFI stock.
- Shortened pipelines (both retrograde and order-and-ship times) improve mission capability.

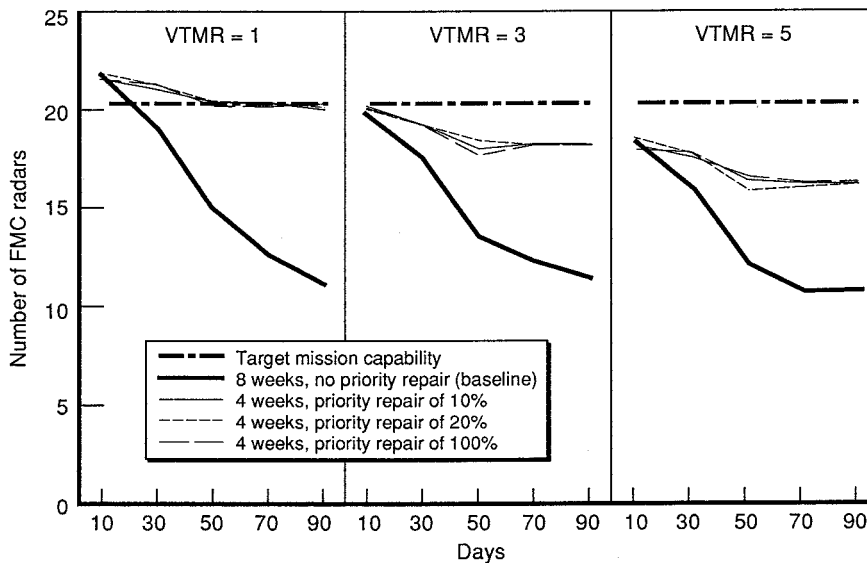


Fig. 3.28—Priority Repair Plus Shortened Pipelines Substantially Improves Mission Capability Regardless of VTMR

Table 3.1
Simulation Results

Variation	Percent Increase in Number of FMC Radars Compared to Baseline Case		
	Day 50	Day 70	Day 90
Repair of all non-RFI stock	12	28	31
Prioritized repair of 10% of non-RFI stock	15	20	26
Shortened pipelines: 3 weeks	31	44	50
Availability AVCAL	13	12	14
Prioritized repair of 10% plus 4-week pipelines	33	50	60
Prioritized repair of 10% plus 3-week pipelines	43	58	70

Table 3.2
Robustness of Results

Variation	Percent Increase in Number of FMC Radars Compared to Baseline Case		
	Day 50	Day 70	Day 90
Repair Capacity Reduced: CV/2, Depot			
Prioritized repair of 10% of non-RFI stock	45	40	41
Shortened pipelines: 3 weeks	67	63	68
Availability AVCAL	25	12	6
Prioritized repair of 10% plus 3-week pipelines	114	116	123
Troublesome Part Removed, 3/4 Repair Capacity			
Prioritized repair of 10% of non-RFI stock	7	13	11
Shortened pipelines: 3 weeks	20	29	26
Availability AVCAL	12	14	11
Prioritized repair of 10% plus 3-week pipelines	28	41	37
VTMR = 5			
Prioritized repair of 10% of non-RFI stock	13	28	22
Shortened pipelines: 3 weeks	27	45	39
Availability AVCAL	12	14	9
Prioritized repair of 10% plus 3-week pipelines	44	58	59

- Replacement of the standard AVCAL, which has many low-demand items, with one that is based on aircraft availability goals has a small but positive effect on the number of FMC radars.
- Priority depot repair combined with shortened pipelines increases the number of FMC radars more than does either of these items separately.

All of these improvements proved to be robust when repair capacity was reduced, a troublesome part was removed from consideration, and demand variability was both increased and decreased.

4. CONCLUSIONS AND RECOMMENDATIONS

We reached three conclusions based on the simulation results and one conclusion based on our experience using Navy data. These conclusions, all of which point to the need to improve the existing data systems so that they will provide effective visibility and decision support, are as follows:

- Priority (rather than first-come, first-served) repair at the depot can make an important difference in mission capability.
- An important ingredient, data synthesis, is missing in the Naval aviation logistics management system. This lack inhibits the depots' ability to react quickly in support of sudden demand peaks.
- Shortened transportation pipelines can yield large improvements in mission capability.
- An AVCAL based on aircraft availability goals may have some promise in maximizing aircraft availability per dollar spent.

Our conclusions and recommendations are examined next. Where appropriate, we tie in considerations from Operations Desert Shield and Desert Storm.

PRIORITY REPAIR AT THE DEPOT

We saw large amounts of non-RFI stock for which break rates were high and RFI stock levels were low. This is a bad situation, and we were unable to understand how it had come to be. We tried to answer the question, What would it be worth in terms of mission capability for the depot to repair the non-RFI stock?

One way to approach the problem is to select the stock to be repaired on the basis of first-come, first-served priority. Another way is to prioritize repair on the basis of which stock maximizes aircraft availability requirements. In the latter case, two things are needed: data (e.g., demand rates, stock levels, flying activity, repair resources) and a method for combining these data so they can be used to prioritize asset repair and asset allocation. Optimization programs for this purpose already exist, or one can be constructed with little difficulty. We applied one and found that prioritized repair of 10 percent of the non-RFI stock most needed for mission capability yielded virtually the same improvement as repairing all of the non-RFI stock.

In a contingency, the Navy seems to expect the depots to surge (as the North Island NADEP did for the T-64 engines needed in Operation Desert Shield). However, the element of uncertainty in such an event means that the Navy will not know far in advance what system(s) to fix, so the surge will probably not be possible until the last minute. The Navy could make tremendous gains in achieving good results in such a case by prioritizing its repair requests. In Operation Desert Shield, for example, the prioritization of North Island's jet engine component repair activities was left to the judgment of individuals who had to make their decisions, without data, in a dynamic and pressure-packed environment.

Recommendation: We recommend that information systems needed for quick response be in place prior to any contingency. Then, when surges are required, the depot can focus all of its resources on repair. Specifically, the Navy should consider

- Systematically constructing complete lists of parts for weapons systems.
- Putting in place data systems that support repair prioritization at the depot. (The next subsection provides additional details.)

BETTER DATA SYSTEMS INTEGRATION

Unforeseen demands force the Navy to rely on the depot's ability to surge. Logistics planners should enhance that ability by establishing activities that are known to be needed in a surge environment. Then, when a surge is needed, the depot can direct its resources to meet the unforeseen demands.

Also, the Navy's resources are expected to decrease over time because of budget constraints. As every part becomes more valuable, it will become increasingly important for the Naval logistics system to know where parts are and for ASO to know how parts are functioning in the active squadrons so that the depot can be tasked appropriately.

We know that some data the depot could profitably use do not exist. North Island personnel told us that in their surge to produce T64 engines during Operation Desert Shield, they had to invest one week (of 16-hour days) up front to build a bill of materials. To support our analysis, North Island spent several weeks building a description of part identifiers and repair requirements (e.g., test stands, person-hours) for the AWG-9 radar.

Navy data systems tend to be insular. Stockage information at NSCs and NASs is separate from that on carriers, demand data are separate from both, and flight activity data are yet someplace else. Different parts and location identifiers are used in each of these files, and no up-to-date crosswalk exists. To understand how the logistics system functions, one must integrate these different kinds of data. It is a major effort, for example, to construct plots as simple as the non-RFI stock plot shown in Fig. 3.2 and the AVCAL plot shown in Fig. 3.7.

Recommendation: We recommend that a capability be established to provide an ongoing link between Navy data files so that an integrated, responsive logistics management system will be possible.

SHORTENED TRANSPORTATION PIPELINES

Our simulations showed the value of shortened pipelines for AWG-9 radar availability during a 90-day war. We found that for the AWG-9 system, which can be almost completely repaired in the carrier's I-level shops, a lack of retrograde stock for depot repair would result in about 60 percent of the radars being out of commission by day 90 if the radars were heavily used. And for hydraulics or engine systems, where shipboard repair is quite limited, ignoring the retrograde stock could make matters much worse.

The retrograde times in Operation Desert Shield were enormous. That aspect of the logistics system was virtually ignored: returning retrograde stock to the depot was given a very low priority. We have been told that ASO had no visibility of retrograde stock until late November 1990. North Island had received only six retrograde T64 engines through the end of February 1991. Transportation is crucial to sustaining a high flying program longer than that recently experienced in the Persian Gulf.

Recommendation: The Navy's transportation system provides for constant resupply among the carriers, NASs, NSCs, and depots. But parts currently flow through the system very slowly. We recommend that the present transportation pipelines be examined to determine where bottlenecks occur, so that the cost of making the system more efficient can be estimated. Future wartime planning should place greater emphasis on responsive transportation of stock both to and from repair facilities.

AVCAL SELECTION

Negotiators at the AVCAL conference focus on items, with aircraft availability as their primary goal. But aircraft availability calculations are too hard to do in one's head. One would have to keep numerous interrelationships in place (e.g., repair resources, asset availability, demand rates) while trying to stay within a fixed budget and deal with thousands of parts.

Recommendation: We recommend that the Navy consider a decision support system that organizes the necessary information across the entire range of the AVCAL and stocks according to availability goals.

In investigating priority repair, we used an algorithm that planned according to availability goals and saw the striking result we described earlier: judicious selection of 10 percent of the non-RFI items for repair leads to the same improvement in mission capability as fixing all non-RFI items. Applying this algorithm to AVCAL selection produced an AVCAL (its properties are displayed in Figs. 3.7 and 3.8) that seemed quite reasonable. The new, *availability* AVCAL had fewer low-demand parts and more high-demand parts than the standard AVCAL. Our simulations based on this stockage posture showed positive effects.

Recommendation: We know that these results alone are not a sufficient reason to overturn long-standing Navy practice. But as budget pressures increase, the importance of reaching for optimality will grow. In anticipation of these pressures, we recommend that the Navy experiment now with alternative algorithms for AVCAL selection.

Appendix A

RELATED RAND LOGISTICS STUDIES

RAND has a comprehensive record of logistics research for the Air Force and Army and a less extensive record of research for the Navy. Following are brief summaries of prior RAND logistics studies that influenced this report.

NAVY LOGISTICS STUDIES COMPLETED AT RAND

The first RAND study that looked specifically at Navy aviation logistics was the Defense Resource Management Study (DRMS) commissioned by the Secretary of Defense in November 1977. One of the five topic areas of that study was *logistics support of combat forces*, which highlighted Navy carrier-based air logistics support. Policies were identified that had the potential to improve peacetime readiness (defined as number of mission-capable airplanes) and wartime operational performance. Two of the recommendations are still valid today: (1) an enhanced stock distribution system that accounts for operational information in repair and distribution assignments and (2) a more responsive transportation system that allows a trade-off between supply and transportation.

Upon completion of the DRMS, RAND was asked to evaluate the study's recommendations in more detail. The Carrier Based Air Logistics (CABAL) study examined logistics policies for avionics equipment that held potential for improving aircraft availability and wartime sustainability. It looked at the recommendations from the DRMS study and at other recommendations that would require less structural change for the Navy. It concluded that (1) Navy retrograde and order-and-ship times are exceedingly long, (2) priority repair can increase aircraft availability and reduce cannibalization requirements, (3) increasing the AVCAL range provides protection against demand uncertainty, and (4) establishing stock levels based on aircraft availability rather than requisition fill rate would significantly improve mission capability.

Several smaller studies examined specific topics for the Navy. The report *Depot Maintenance of Aviation Components: Contractor vs. Organic Repair* (Embry et al., 1985) discussed the implications of alternative source-of-repair decisions. That work provided a strategy

for assessing the appropriate repair source at distinct points in the weapon system and subsystem life cycle.

Two other studies concentrated on the need for peacetime planning of wartime demands. A model that could be used to forecast wartime depot-level component repair workloads was described in *Forecasting Wartime Depot-Level Component Workloads* (Moore, Embry, and Day, 1985). That analysis highlighted potential trade-offs among stock, distribution, and repair, and demonstrated that the timing and magnitude of the depot workload are sensitive to distribution and repair times as well as to sortie and attrition rates. Carrillo and Schank's (1985) *Assessment of the Wartime Logistics Support System for Navy Aircraft Engines* reviewed the Navy requirements processes, concentrating on the operational scenarios, support structures, goals, models, and performance characteristics used in requirements computations. That analysis suggested that (1) resourcing scenarios should be approved at high levels and published for use in the various resource requirement computations relating to engine logistics support; (2) differences between planned and actual peacetime performance characteristics, such as removal rates and pipeline times, need to be reconciled; (3) appropriate models that adequately represent the operational environment (including its three-echelon support structure) should be used to calculate resource requirements; and (4) similar integrated analysis of other logistics resources for aircraft engines should be performed.

OTHER RECENT LOGISTICS RESEARCH AT RAND

Characterization of Demand

RAND reports by Crawford (1988) and Hodges (1985, 1988) describe variability in peacetime demands for avionics parts. This acknowledgment of the demand variability in peacetime led to two important questions: (1) Do our mathematical models of supply and repair systems accurately deal with this variability? and (2) If variability is great in peacetime, what will it be in wartime?

RAND used mathematical models to study the performance of the Air Force's spare parts supply and repair systems. These models depend on accurate modeling of the demand process for parts and the variability within that process. If such models do not accurately reflect the true variability in demands, their results will be biased in favor of policies that assume accurate predictions of failures. In his report *Modeling the Demand for Spare Parts: Estimating the Variance-to-Mean Ratio and Other Issues*, Hodges (1985) noted that the ability to

predict levels of parts failures is strongly affected by at least two types of uncertainty: the number of failures that will occur assuming the model is correct, and the adequacy of the model as an approximation of the demand process for spare parts. Hodges suggested that a model allowing more variability, such as a negative binomial model, would be more appropriate for dealing with the first type of uncertainty, and that the second type can be accommodated in part by using models with more parameters.

How to manage the uncertainty and modeling difficulties described by Hodges and Crawford led to several long-term studies for the Air Force—CLOUT and DRIVE. The CLOUT (Coupling Logistics to Operations to meet Uncertainty and the Threat) study found that it was more beneficial to rely on management adaptations than on stock purchasing to mitigate the consequences of uncertainty. It showed that significant gains can be achieved from alternative policies for distribution and lateral repair and supply. Aircraft availability was shown to increase when the depot repair system was able to respond quickly to the operational needs of the squadrons. The DRIVE study developed a depot-level repair prioritization and asset allocation scheme that was shown to be more adaptive to demand variability than the current Air Force system and thus could be used to achieve a higher level of aircraft availability for a specified cost.

Reliability and Maintainability—Bad Actors

RAND studied the combat-performance implications of failure in high-performance avionics. The failure of equipment to perform as designed and the efficiency of maintenance for detecting faults was evaluated by Gebman, Shulman, and Batten (1988b) in what is known colloquially as the *Bad-Actors Study*.¹ The report, *A Strategy for Reforming Avionics Acquisition and Support*, provided six suggestions for correcting these problems: (1) accelerate repair-and-maintenance-related avionics technologies, (2) improve the ability to test avionics equipment, (3) provide more complete feedback on equipment performance, (4) adopt a maintainability indicator, (5) institute maturational development, and (6) reorganize the Air Force's avionics engineering resources. The report also provided results from a development effort aimed at repair and maintenance of fire control radars on the F-15C/D and the F-16A/B.

¹Bad actors are parts that persistently fail to perform as designed and have faults that are hard to detect. Their existence stems from problems in the acquisition and support processes of avionics.

Appendix B

PLANNING FOR PARTS FAILURES ON THE AWG-9

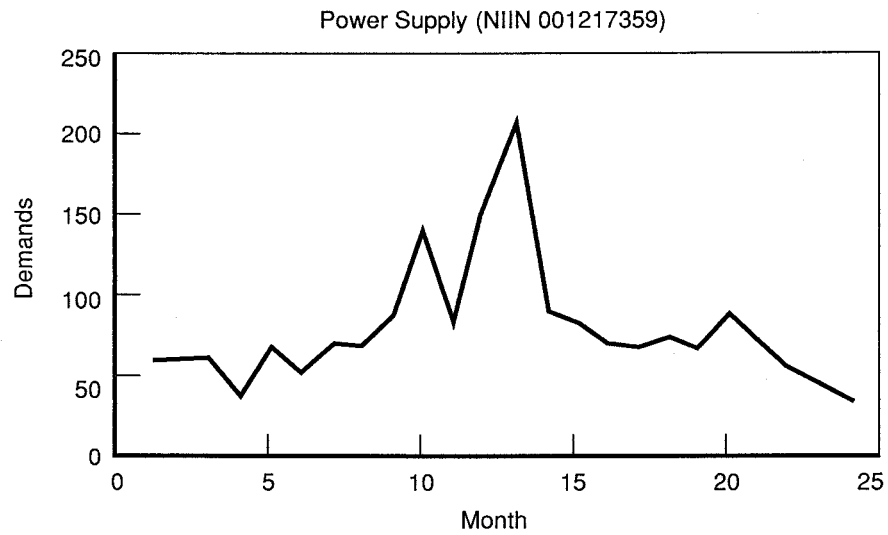
FORECASTING

Improvement in the prediction of aggregate parts failures has often been pursued as an approach to limiting the risk of stock-outs. Such predictions use historical data on previous demands and planned operations tempo to project the number of breaks. Improvements focus on collecting better data or using more-sophisticated statistical models. However, RAND research in both Air Force and Army logistics has indicated that it may be impossible to accurately predict demands over the entire range of spare parts in a given weapon system because some parts show wide swings in demand over time. Further, the parts experiencing large variations change with time. Our analysis of data on AWG-9 parts failures bears this finding out.

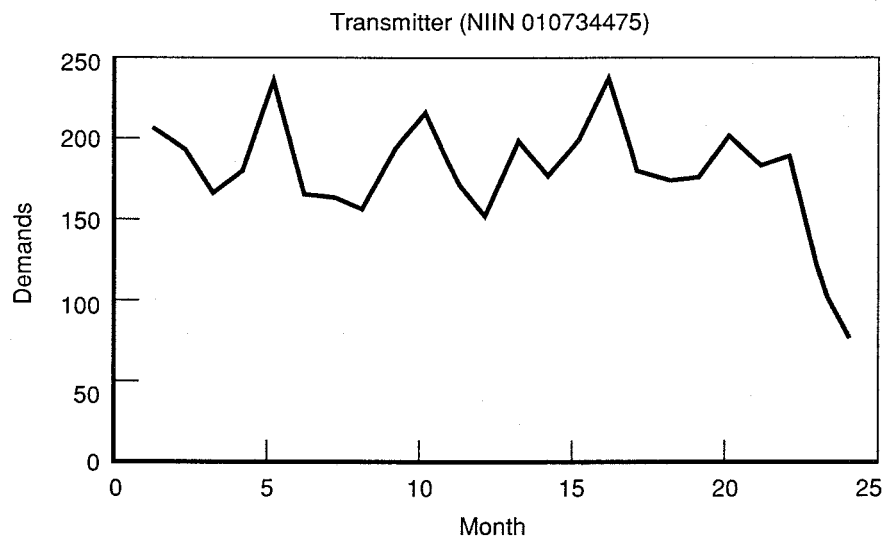
We illustrate these points with data from the 3M system on AWG-9 repairs at all Navy installations from 1987 to 1988. After processing to identify intermediate-level repair actions, we aggregated the data by month. We first show an example of how the demand for a part can change radically in a short time.

Figure B.1 shows the I-level demands per 100 flying hours for the AWG-9 power supply. In early 1988, the demand rate increased by 400 percent, which, with about 10,000 F-14 flying hours logged per month, is an increase in repair actions from about 60 to over 200 per month. In contrast, the demand rate for the AWG-9 transmitter (see Fig. B.2), which is also fairly high, was more consistent, averaging 200 repair actions per month. The 400-odd parts making up the AWG-9 show a wide range of behaviors—from very low, consistent demands to very high, extremely variable demands.

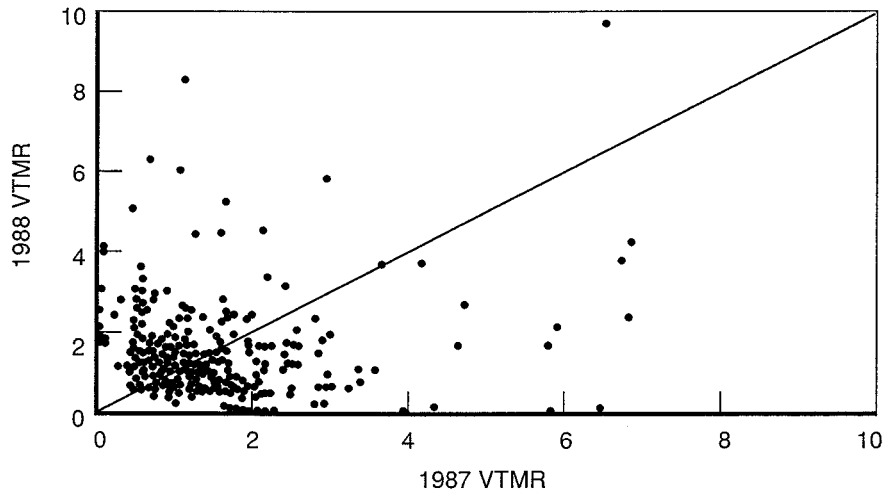
A measure of variability is the VTMR. For the third graph, Fig. B.3, the 1987–1988 data were divided into two separate years and the VTMR was computed separately for each year for each part. If the VTMR saw no change from 1987 to 1988, each point would lie on the 45-degree line from the origin. As can be seen, the VTMR changed substantially from year to year for a large number of parts. This result means that safety stock computed from 1987 data for parts whose VTMR increased would be inadequate to meet the demand in 1988. Conversely, parts whose VTMR decreased would end 1988 in excess supply.



**Fig. B.1—Monthly Demands per 100 Flying Hours
for AWG-9 Power Supply**



**Fig. B.2—Monthly Demands per 100 Flying Hours
for AWG-9 Transmitter**



**Fig. B.3—Plot of VTMRs for Break Rates of AWG-9 Parts
in 1987 Versus 1988**

These findings are consistent with those of a number of other studies done by RAND for both the Air Force and the Army. An analysis of F-15 parts demands for the Air Force showed that the change in VTMRs was found in the demands for many different parts (Crawford, 1988). In an analysis of avionics parts for Army helicopters, a comparison of demands during normal flying, intense training, and combat operations during Operation Just Cause showed that some parts with high failure rates in training had very few failures in combat, and vice versa.

The reasons for such variability are not known with certainty. Equipment modifications, new missions and tactics, and changing maintenance procedures probably all play a part. The lesson is that while better data and reliable prediction methods are useful tools in managing spare parts, anomalies such as the ones illustrated here will always occur. To handle such problems, a responsive repair and procurement system is essential.

BUY-OUT

One proposed solution to uncertainty is to buy it out, i.e., to purchase enough safety stock to provide a high probability of not running out of any item. The problem with this strategy is that it becomes expensive when demands are highly variable. We used RAND's DRIVE algorithm to compute a spares kit for the AWG-9 to cover a 90-day war without resupply, assuming that all parts have the same VTMR. When the common VTMR increases from 1 to 3, the cost of the spares kit increases by 84 percent (the VTMR = 1 spares kit is itself roughly twice the cost of the AWG-9 spares kit stocked in the typical AVCAL). Some parts with high demand rates have VTMRs of 5 to 10, and such parts are usually quite expensive. Covering these demands could double or triple the cost of the kit.

In any case, the changing variability in the demand process for many parts means that stock-outs will still occur for some items, while other items will end up in excess supply, even with the increased expenditures.

Appendix C

ACQUIRING AWG-9 DATA

This appendix describes the steps we took to acquire and prepare the data needed by the Dyna-METRIC simulation program. We highlight the difficulties we faced as background to our recommendation for better data synthesis.

We identified three sources for needed data:

- NAMSO, whose 3M data provided usage information on parts and airplanes.
- ASO, which has data files on assets, parts configurations, acquisition costs, and repair requirements.
- North Island (San Diego) NADEP, which has information on the AWG-9 system.

We also compiled several data sets of our own, mostly crosswalks to link the various data sets with different location and parts identifiers. Processing the information required that we

- Learn what was available.
- Acquire the information.
- Decide what variables were important to us, examine their values, and try to understand them.
- Aggregate information across records.
- Develop crosswalks to link the different files together.

The following subsections describe how we applied these steps to the raw data from each source and then how we processed the data and combined them for our Dyna-METRIC simulation runs.

NAMSO (3M) DATA

The 3M data from NAMSO provide flying intensity and breakage information. Flying information is contained in a naval flight records file called NAVFLRS; breakage information is in a trouble report file called VIDS/MAF. A sense of the relative quality and importance of data items can be gained only by interviewing the people responsible

for their recording and organization. To do this, we visited NAMSO Headquarters, observed flight-line operations at several locations, and visited intermediate-level repair facilities at several locations.

NAVFLRS

At the conclusion of each flight, the pilot completes a detailed report called the NAVFLRS. This information is eventually entered into a computer and sent to NAMSO, which organizes and manages the information. NAMSO sent us a data tape containing all F-14 flights for calendar years 1988 and 1989.

The useful variables on this file were

SQUAD	squadron
DATE	date of flight
TOTFTIM	total flight time

We aggregated total flight time by date and by squadron. This aggregation told us what the normal levels of flying activity were for the F-14 and thus helped us choose flying program parameters for DYNAMETRIC. It also entered into our break-rate calculations (see below).

VIDS/MAF Records

If the pilot encounters any problems during a flight, he completes a detailed report called the VIDS/MAF form. This form is filled out at the end of the flight and handed over to organizational-level personnel, who attempt to determine which WRA caused the problem and to replace that WRA if they think it is broken. Regardless of the status of the WRA, these personnel document what they did on the VIDS/MAF form. If they think the WRA is broken, they send it to the intermediate repair facility, which further diagnoses the problem and attempts to fix the WRA.

Every action relating to the original problem is entered on a VIDS/MAF form. However, no attempt is made to capture all of the maintenance actions for a single problem on a single form: new forms with the same *job control number* are routinely opened up. This information is keyed into a computer and sent to NAMSO. They provided us with a data tape of all VIDS/MAF reports for calendar years 1988 and 1989.

Variables on the file that proved useful were

SQUAD	squadron
DATE	date of flight
JCN	job control number
WUC	part identifier (called the <i>work unit code</i>)
LEVEL	level of repair (organizational or intermediate)
MALCOD	malfunction code
BCM	a <i>beyond-the-capability-of-maintenance</i> indicator meaning the part was sent to the depot for repair
TFTIM	total flight time

More than one VIDS/MAF record may be filled out for a reported problem, and the report may result in the discovery that no break occurred. To identify maintenance action (or lack of action) from a pilot's report, it is necessary to group VIDS/MAF records together and examine them in the aggregate.

We grouped records by job control number and work unit code. Within each group, we considered a part broken only if the records showed it reached an I-level repair facility and was assigned a *malfunction code* indicating *broken*; otherwise, we considered that series of VIDS/MAF reports a false alarm. If a break occurred, the record confirming the break might also indicate that the I-level shop was not capable of fixing the part, in which case the item was classified *BCM*. Having thus eliminated several VIDS/MAF forms in each case that described maintenance actions related to a break, we were able to count actual breaks and BCM actions by any of several conditioning variables: work unit code, squadron, and date of flight.

We next attempted to link and aggregate NAVFLRS and VIDS/MAF data by date and squadron. We lined up part failures with flying intensity to select cases in which the population of aircraft in the NAVFLRS data coincided with the population in VIDS/MAF data. We then calculated demand rates and the variance of demand rates over time for use by Dyna-METRIC.

ASO DATA

ASO data provided basic information on assets. For every NAS and NSC, ASO keeps records on the number of parts of each type in vari-

ous conditions. Moreover, ASO maintains files that describe carrier AVCALs and back orders. We did not have stock levels for carriers, so we had to infer them from knowledge of their program planning requirements and back-order requests.

Stock at NASs and NSCs

ASO's *TRLRN* file contains some variables that we thought would be useful:

NIIN	part identifier
ASC	location identifier
COND	condition (A, F, G, or M)
ONH	number of parts on hand
DIFM	number of parts due in from maintenance

We acquired the information by logging onto ASO's FOCUS computing system and pulling the inventory down over the telephone lines for NIINs that we determined to be on the AWG-9.

The data were quite clean. We defined total stock as (ONH+DIFM), broke the stock down by condition (COND), and summed stocks by part number within each location (ASC).

Locations were coded here according to a four-character code (ASC). This code was not present on other types of records. We built a crosswalk file that linked records by location. Another kind of link was by part number. ASO used NIINs to identify parts; the 3M files (described in the previous subsection) used WUCs (work unit codes). We also built a crosswalk file for WUCs and NIINs.

Stock on Carriers

We were unable to get carrier asset information, so we attempted to infer it from a two-step procedure:

1. We obtained a file—the PPR file—that identified what the carrier had requested and was promised.
2. We assumed that, as the carrier was deployed, it would generally get what it asked for, except as noted on ASO's back-order files. ASO had two such files: DSFINC, which contained partially filled cases, and DSFBOF, which contained completely unfilled requests.

We accessed both of those files to determine how short the stock on the carriers was, and subtracted that amount from the PPR total.

Each of these three files contained

NIIN	part identifier
RIC	location identifier
QTY	number of parts on hand (PPR) and back ordered (DSFINC, DSFBOF)

As was true for the other ASO files, we were able to access these files on the FOCUS system and retrieve their data over the telephone lines.

The data again were quite clean. We summed stocks by part number within each location and defined the stock on hand as the PPR quantity minus the sum of quantities in the two back-order files.

NORTH ISLAND DATA

The North Island NADEP identified the parts of the AWG-9 radar and several key characteristics of those parts:

NIIN	part identifier
PARTNO	part number
LEVEL	level of indenture (WRA or SRA)
NIIN0	identifier of SRA's parent
NOMEN	nomenclature
WUC	work unit code (a seven-character part identifier)
WLSTD	workload standard (billable time to fix the part)
DSTAND	test stand for this part at the depot

This file gave us the indentured relationships that Dyna-METRIC needed. Also, because it contains both NIINs and WUCs, it enabled us to link ASO information about NIINs to the 3M information about WUCs.

RAND-BUILT DATA FOR LINKING NAVY DATA FILES

For the information in the Navy data files to be useful, the files had to be linked together. However, there was neither a common link variable nor a readily available crosswalk file to use. For example, here are the kinds of considerations we faced in putting together a simple plot of systemwide RFI assets versus demand rates (as seen in Fig. 3.2):

- *Parts.* For each WRA and SRA on the AWG-9, we needed to know four different identifiers: NIIN, WUC, part number, and item identification number (IIC). ASO and the depots identify stock by NIINs, IICs, and part numbers; carriers and NASs identify breaks by WUCs and sometimes part numbers. IICs must be mapped into NIINs and NIINs into WUCs, but there are no complete crosswalks anywhere. Furthermore, NIINs change over time. An ASO file called *JSS* tells you about such changes, but *JSS* is itself a snapshot that changes over time. Contractors use part numbers and sometimes NIINs to identify parts. A part may have more than one part number if it is manufactured by different contractors or has different vintages.
- *Locations.* Stock levels for NASs and NSCs use four-digit codes called activity sequence codes (ASCs); stock levels for carriers use five-digit codes called requisitioner identification codes (RICs). VIDS/MAF and NAVFLRS use squadron identifiers, organization codes, permanent unit codes, and wing codes. Locations for squadrons change over time; in addition, they are not machine readable, coming instead from hard-copy reports. And even when the hard copy is considered, there are still no complete crosswalks for locations.

Using information gained from telephone conversations and from various documents we obtained through contacts with ASO personnel, we compiled some additional files:

1. *ID.* This file links information from different files with different location identifiers (ASC or RIC). It also indicates which bases are carriers, NASs, or NSCs.
2. *COMNIIN.* Since part identifiers can change over time even though the parts are functionally identical, we mapped all such parts into a common NIIN.
3. *VFLOC.* This file contains squadron-carrier assignments, which we use to relate flying activity for squadrons (identified by SQUAD x DATE) to location.

4. *MIS*. This file holds miscellaneous information about parts, including DEPOT (whether the part is fixable only by the depot), QPA (quantity per application), and STAND (whether there is a test stand for this part at the I-level shop).

Appendix D

DYNA-METRIC DATA INPUTS

Defining the Dyna-METRIC runs entailed specifying options to characterize the simulations and describing the characteristics of the AWG-9 radar. Brief descriptions of the data sets we compiled are given in Tables D.1 through D.4. The Dyna-METRIC documentation (Isaacson and Boren, 1988; Isaacson et al., 1988) describes the inputs required in some detail.

Describing the characteristics of the AWG-9 radar required aggregating and linking various pieces of the information we acquired (see App. C). While there were many sources of information to deal with during this process, the steps were straightforward relational data-management operations and thus are not described here.

Ultimately, we produced a list of AWG-9 WRAs and SRAs indicating their indentured relationships, their quantities per application, the rates at which they break, how the break rates vary over time, whether each break was fixed only at the depot, the BCM rate (for parts repairable on the ship, which were most of them), how long it takes to fix the parts, the repair facilities available on the carrier and at the depot, and the stock on the carrier as well as at the depot (NSC).

Table D.1
Dyna-METRIC Parts Data

Item	Description
WRA description	Failure, repair, and resupply characteristics of each WRA. Repair time is the time the repair resource is exclusively dedicated to the WRA (excluding time spent in the queue).
SRA description	Failure, repair, and resupply characteristics of each SRA. Repair time is the time the repair resource is exclusively dedicated to the SRA (excluding time spent in the queue).
Indentured relationship	Relationship between WRAs and SRAs. All SRAs must be indentured to at least one WRA.
Applications fraction	Proportion of each carrier's or NAS's aircraft on which the WRA is installed.
Repair assignment	Specification of which parts are assigned to each repair resource. Repair resource records describe the availability of test equipment and the parts that are repaired on each test bench.
Server level	Number of available servers per repair resource at each location. Servers may be test stands or some other repair resource whose quantity or availability may limit the number of parts repaired in a given time period.
Stock level	Stock levels at each NSC, carrier, and NAS for each part.

Table D.2
Dyna-METRIC Descriptions of Repair Resources

Item	Description
Depot	Characteristics of each depot, including its resupply availability and when repair of WRAs and SRAs starts.
NAS	Characteristics of each NAS, including its resupply availability and when unconstrained repair of WRAs and SRAs starts.
Carrier	Characteristics of each carrier, including its connection to a NAS (if any), resupply availability, and when unconstrained repair of WRAs and SRAs starts.
Depot transportation	Information on the transportation resources connecting carriers or NASs with depots.

Table D.3
Dyna-METRIC Scenario Data

Item	Description
Aircraft and sorties	Number of aircraft assigned to each carrier or NAS, average daily number of sorties per aircraft on each carrier or at each NAS, and maximum number of sorties an FMC aircraft can fly per day on each carrier or at each NAS.
Attrition rate	Proportion of aircraft lost per sortie during combat operations on each carrier or at each NAS.

Table D.4
Dyna-METRIC Miscellaneous Data

Item	Description
Administrative data	Carrier, NAS, and depot administrative times, as well as information about lateral resupply. Because carriers do not engage in formal lateral resupply, we ignored that option.

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