RAND

Using Value to Manage Repair Parts

A Documented Briefing

Marygail K. Brauner, James S. Hodges, Daniel A. Relles

Arroyo Center

The research described in this report was sponsored jointly by the Navy Secretariat, Naval Air Systems Command (NAVAIR-43), Naval Supply System (NAVSUP), and the Navy's Aviation Supply Office (ASO).

Library of Congress Cataloging in Publication Data

Brauner, Marygail K., 1947–
Using value to manage repair parts / Marygail K. Brauner, James S. Hodges, Daniel A. Relles.
p. cm.
"Prepared for the United States Army and United States Navy."
"MR-311-A/USN."
ISBN 0-8330-1436-6
1. United States. Navy—Aviation supplies and stores. 2. United States. Navy—Inventory control. 3. United States. Navy—Equipment—Maintenance and repair. I. Hodges, James S. II. Relles, Daniel A. III. RAND. IV. United States. Army. V. United States. Navy. VI. Title.
VG93.B724 1993
359.9'4834—dc20 93-28005
CIP

Published 1993 by RAND
1700 Main Street, P.O. Box 2138, Santa Monica, CA 90407-2138
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Approved for public release; distribution unlimited

PREFACE

This document contains the charts and text of a briefing given to senior leadership in the Defense Logistics Agency and the Naval Supply System in February 1993. The briefing describes (1) the history of the RAND Navy research initiative that led to RAND's examination of how to manage repair parts, (2) an approach to stocking parts at a Navy depot, (3) a description of how to develop authorized stock levels based on the *value* of parts, (4) an evaluation of authorization policies, and (5) a discussion of future directions the research might take.

This work is part of a larger RAND project entitled *Enhancing the Logistics System: The Depot Perspective*, sponsored jointly by the Navy Secretariat, Naval Air Systems Command (AIR-43), Naval Supply System, and Aviation Supply Office. When this project began in 1989 it had three objectives:

- Improve the readiness and sustainability of Naval aviation
- Improve the integration of Naval aviation logistics
- Identify cost reduction opportunities.

The RAND report *Improving Naval Aviation Depot Responsiveness* (R-4133-A/USN by M. K. Brauner, D. A. Relles, and L. A. Galway, 1992) documents some of the work completed on the first two objectives. This documented briefing presents work on the third objective.

Our mandate in this project includes suggesting and analyzing broad policy issues, as well as offering more detailed suggestions. RAND work on the broader policy issues is described in the aforementioned report and in two additional RAND documents: *Materiel Problems at a Naval Aviation Depot: A Case Study of the TF-30 Engine* (N-3473-A/USN, 1992) and *Management Adaptations in Jet Engine Repair at a Naval Aviation Depot in Support of Operation Desert Shield/Storm* (N-3436-A/USN, 1992), both by L. A. Galway.

It is hoped that Naval maintenance and supply officers will find this work of interest. And given that some of the problems faced by the Naval aviation logistics system are common to all services, this work may also be of interest to logisticians in the other services and in DoD.

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SUMMARY

BACKGROUND

Our earlier work and conversations with Navy personnel suggested that material support is an important problem for the Naval aviation depots (NADEPs). Even with the current level-repair schedules, depot artisans often do not have the repair parts (both consumables and repairables) they need to complete repairs without undue delays. In this research, we sought to quantify the cost to the logistics system of not having readily available repair parts. Better availability of parts might reduce turnaround time (TAT) in NADEPs, thereby bringing more weapon replaceable assemblies (WRAs) into ready for issue (RFI) condition. We note that materiel availability seems to be a systemic problem in aviation repair; for example, commercial airlines also experience long delays in the repair process due to lack of parts.

The Navy recognizes these materiel problems and has suggested that parts be stocked in the depots in much the same way they are stocked on deploying aircraft carriers. Aircraft carriers stock parts to sustain flying operations for three months without resupply. This stock is called an AVCAL (Aviation Consolidated Allowance List). Navy personnel have proposed an analogue for NADEPs—i.e., a NAVCAL .

PURPOSE

This document presents a method for examining how various stockage policies affect the length of time WRAs spend waiting for parts. As a first step, we developed a value measure for parts; then, using value, we created ranked lists of parts to stock at the NADEPs. *Value* is essentially a part's contribution to reducing the time a WRA spends waiting for parts. If a part breaks frequently and tends to hold up the repair of an expensive end item, then it is very *valuable.* Since this briefing was given, we have refined the methodology and have devised an additional method for evaluating the short-run effect of supply actions on aircraft availability. This work is documented in *Models and Algorithms for Repair Parts Investment and Management,* MR-314-A/USN (forthcoming), by James S. Hodges.

DATA SOURCES

In our computations, we used data the Navy routinely collects—Navy Inventory Materiel Management System (NIMMS) data from the NADEPs and price information from the Aviation Supply Office (ASO). The former data describe which end items were repaired, what parts were used to repair them, and how long the end items waited for the parts. The latter provide each end item's unit price and helps us link up information from disparate sources.

RESULTS

Current stockage policies emphasize descriptors of parts (unit price, failure rates) and rarely include information about the end item that needs the parts (i.e., the item whose repair is affected by their availability). It is likely that this situation contributes to the simultaneous problems of long repair TATs and excess repair parts.

We developed an algorithm that minimizes the expected length of time an end item spends in repair. The method incorporates both parts descriptors (such as unit price and failure rates) and output measures (such as repair throughput time and unit price of the end item).

Our research suggests that through effective stockage of repair parts, the Navy may be able to achieve large savings. Those savings come from shortening the TAT at the depot, which then allows more end items to be in circulation. Furthermore, our evaluations suggest that our calculations can identify weapon systems for which it would make sense to stock parts and those for which it would not. The calculations can be used to balance investment strategies between spending money on parts and spending it on other segments of the repair pipeline. Since this briefing was given, we have refined the methods and developed an additional method for evaluating the effect of supply actions on aircraft availability. We believe that our results make the case for experimenting with our methods at a depot. We recognize that other processes (order-and-ship times, setup times, replacement factors, etc.) are also important to achieving an efficient depot, perhaps more important than clever stockage. Thus, setting policy on parts stockage is only one part of a much larger redesign process that must occur at the NADEPs if they are to be a cost-effective source of aircraft maintenance in today's defense environment.

RELATED PUBLICATIONS

Two additional RAND reports document this work. The first, *An Approach to Understanding the Relative Value of Parts*, MR-313-A/USN (forthcoming), by Marygail K. Brauner, James S. Hodges, and Daniel A.

Relles is a much more detailed discussion of the topics covered in the briefing. It goes into more depth on the methods, including the motivation behind them, and describes the data, analytical findings, and simulations that someone familiar with military logistics would need to replicate the work presented in the briefing. It also discusses the proposed depot demonstration. The second report, *Models and Algorithms for Repair Parts Investment and Management,* MR-314-A/USN (forthcoming), provides the mathematical underpinnings of these methods and is intended for a technical audience.

ACRONYMS AND DEFINITIONS

ACW	average customer wait
ASO	Aviation Supply Office
AVCAL	Aviation Consolidated Allowance List
AWG-9	radar system for F-14 aircraft
AWP	awaiting parts
BOM	bill of materials
DLA	Defense Logistics Agency
FFRDC	federally funded research and development center
FMC	fully mission capable
ICP	inventory control point
NADEP	Naval aviation depot
NADEPCAL	Naval Aviation Depot Consolidated Allowance List
NAVCAL	Naval Aviation Consolidated Allowance List
NAVSUP	Naval Supply System
NIF	Naval Industrial Fund
NIIN	national item identification number
NIMMS	Navy Inventory Materiel Management System
NRFI	not ready for issue
OST	order-and-ship time
RF	replacement factor
RFI	ready for issue
ROI	return on investment
SMIC	special material identification code
SRA	shop replaceable assembly
TAT	turnaround time
UPA	units per application
WRA	weapon replaceable assembly

Using Value to Manage Repair Parts

Marygail Brauner
Jim Hodges
Dan Relles

February 1993

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RAND's work for the Navy has centered on enhancing logistics responsiveness and integration from the depot perspective. This project has placed special emphasis on the repair of weapon replaceable assemblies (WRAs). A key element in the timely repair of WRAs is having the repair parts (piece parts and shop replaceable assemblies [SRAs]) available when they are needed. The unit price of a part is readily available, but the *value* of the part is not apparent. This briefing describes a method for calculating the value of a part and shows how this value might be used.

RAND Conducts Research on National Security and Domestic Issues

- **RAND is a nonprofit corporation**
  - **Receives funding from contracts and grants**
  - **Operates four federally funded research and development centers (FFRDCs)**

- **RAND's research characteristics**
  - **Policy orientation coupled to research depth**
  - **Multidisciplinary approach to problems**
  - **Long-term relationships with sponsors**
  - **Wide circulation of research products**

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Before beginning the substance of the briefing, we provide some background on RAND and the types of research it conducts.

RAND is a nonprofit corporation. Its support comes from federal, state, and local governments, from foundations and private-sector philanthropic sources, and from its own endowment. RAND operates four FFRDCs—Project AIR FORCE, the Arroyo Center (for the Army), the National Defense Research Institute (for the Office of the Secretary of Defense), and the Critical Technologies Institute (for the Office of Science and Technology Policy).

RAND stresses policy research that frequently cuts across disciplines. Its sponsor of longest standing—40+ years—is the U. S. Air Force, but RAND's goal is to establish long-term relationships with all of its sponsors. Such relationships enhance RAND's ability to provide insights on problems that confront those sponsors. The products of RAND research are placed in the public domain.

The Navy Asked RAND to Look at Aviation Depots

- **RAND has been involved in logistics research for many years**
- **Much RAND research has been implemented by the services**
- **Existing logistics models developed at RAND might be useful to the Navy**

Funding was provided by the Navy Secretariat, AIR-43, NAVSUP, and ASO

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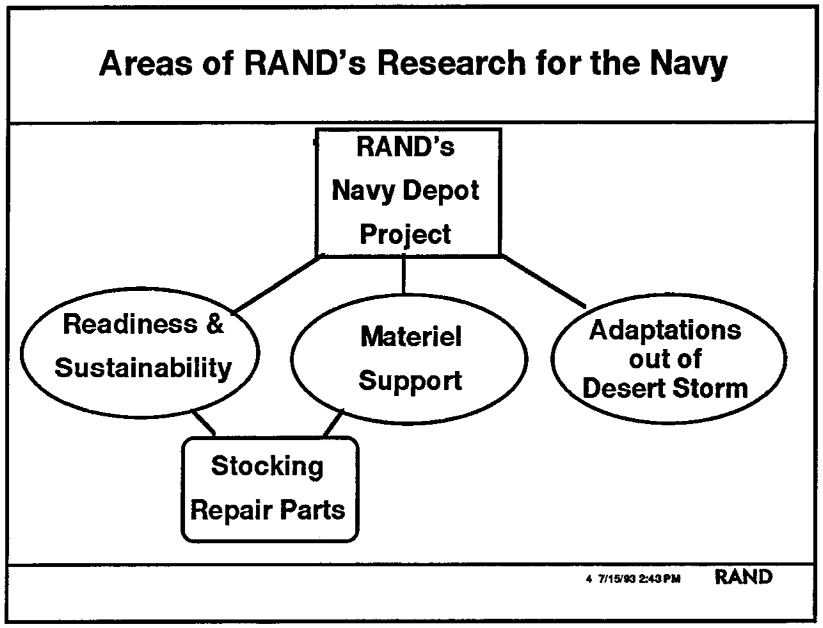
RAND has a long history of logistics research—linear programming, the Berlin Airlift Model, inventory control theory, weapon system management, demand characterization, base-depot simulation models, METRIC, and Dyna-METRIC. In both the public and military sectors, RAND's logistics research has concentrated on the operational implications of logistics policy. The Navy, aware of this research record, asked RAND to study its aviation maintenance depots. The premise was that some of the logistics models and methods developed at RAND and implemented by the Air Force and the Army might also be of use to the Navy. We used both the Dyna-METRIC and DRIVE models in Navy research previously reported on, but a whole new methodology was developed for the research reported in this document.

Funding for the research came from a broad base within the Naval community—the Navy Secretariat, Naval Air Systems Command (AIR-43), Naval Supply Command (NAVSUP), and Aviation Supply Office (ASO).



At a 1989 conference of senior Naval logisticians and RAND researchers at the Naval Postgraduate School, Monterey, California, all Navy participants agreed on one point: the Naval aviation depots (NADEPs) have a "materiel problem." More precisely, there was a consensus that repair processes at the NADEPs are often brought to a halt because parts needed to accomplish the repair are not available. However, there was no consensus on the source(s) of the materiel problem because materiel support in the Navy is the responsibility of several different functional organizations, each with its own perspective, concerns, and performance measures.

In the time since that conference, RAND's research has covered the three broad areas shown in the chart above. Studies were done to determine how the Navy could link the readiness and sustainability of the fleet to repairs done at the depots. This work is documented in *Improving Naval Aviation Depot Responsiveness*, R-4133-A/USN, 1992, by M. K. Brauner, D. A. Relles, and L. A. Galway. The basic findings of this research were that (1) priority repair of not-ready-for-issue (NRFI) radar parts by the depot could significantly improve the number of fully mission capable (FMC) radars, (2) shortened pipelines (both retrograde and order-and-ship times [OSTs]) could improve mission capability by 30 percent or more, and (3) a combination of priority repair and shortened transportation pipelines increased the number of FMC radars by anywhere from 33 to 70 percent.

Materiel support at the depots in peace and war was also studied. The peacetime materiel support research has been documented in working drafts and in *Materiel Problems at a Naval Aviation Depot: A Case Study of the TF-30 Engine*, N-3473-A/USN, 1992, by L. A. Galway. The support for the fleet during the Persian Gulf crisis was impressive; we felt that the adaptations made during that crisis could be informative for future operations. For that reason, depot, intermediate, and organizational repair personnel were interviewed to learn which special actions helped keep aircraft flying during the surge. This information is reported in *Management Adaptations in Jet Engine Repair at a Naval Aviation Depot in Support of Operation Desert Shield/Storm*, N-3436-A/USN, 1992, by L. A. Galway.

From this research and our contacts with Naval personnel, we moved on to investigating the benefits of different depot stockage policies and their ability to increase throughput at the depots. The net result would be more WRAs in RFI status. This document summarizes our research on repair parts stockage policy.

We recognize that for NADEPs to be a cost-effective source of aircraft maintenance in today's defense environment, attention must be paid to both policy—which parts to stock—and process. For it is only by changing policies *and* reducing OST, setup times, routing times, replacement factors (RFs), frequencies of cannot-duplicate errors, etc., that a truly efficient depot can emerge.

We Will Show That a Different Form of Parts Management Has the Potential to Effect Large Savings

- **Current stockage policies emphasize input, not output, descriptors**
- **Consequences of current stockage policies**
  - **Huge excesses accumulate**
  - **Lots of repairable parts are awaiting parts (AWP)**

The Navy has recognized these drawbacks and has initiatives under way: NAVCAL and NADEPCAL

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Our research has shown that by managing repair parts using our methods, the Navy has the potential to achieve large savings. Those savings are achieved by shortening the turnaround time (TAT) at the depot—getting more end items out the door.

Current stockage policies emphasize descriptors of the parts to be stocked (e.g., unit price, failure rates) and rarely include information about the end items whose repair is affected by the parts' availability. It is likely that this situation contributes to the simultaneous problems of long repair TATs and excess repair parts. It is a static system that has great difficulty accommodating change and responding to uncertain demands.

This is not news to the Navy. It recognizes the materiel problems at the depots and has suggested that parts be stocked in the depots in the same way that parts are stocked on deploying aircraft carriers. Carriers stock parts to sustain flying operations for three months without resupply. This stock is called an Aviation Consolidated Allowance List (AVCAL). The Navy calls the proposed stock of depot parts a NAVCAL. In the initial implementation phase, this stock is called a NADEPCAL.

We Have Developed a Method for Managing Repair Parts Based on Some Basic Tenets

- **A view of the repair pipeline**
- **A notion of minimizing WRAs in the repair pipeline**
- **Algorithms to do the minimization**

The thing that makes the algorithm go is attributing "value" to each repair part

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Our research used data that the Navy routinely collects—from the Naval Inventory Materiel Management System (NIMMS) and from ASO.

These data helped us develop a view of the repair pipeline. From them we knew what end items were repaired, what parts they consumed in being repaired, and how long they waited for parts. We developed an algorithm to minimize the length of time end items spend in repair.

The central idea that makes our algorithm work is attributing *value* to each repair part. Simply, **if a part breaks frequently and tends to hold up the repair of an expensive end item, then a spare is very valuable.** The method incorporates both part descriptors, such as unit price and failure rate of the part, and output measures, such as repair throughput time and unit price of the end item that the part goes on.

What Do We Mean by the Value of a Part?

- **We define the value of a part as the reduction in the value of the repair pipeline caused by adding a unit of the part to authorized stock**
- **Value is not just unit price or demand rate; it is a composite of these two things and**
  - **Characteristics of the WRAs the parts go on**
  - **Stocks in the system**

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When a WRA spends lots of time in repair status, the Navy must have extra WRAs just to fill the holes created by the broken WRAs. Thus, if the WRA is very expensive, the Navy will incur large expenses just to cover the repair pipeline. These expenses can be reduced if stocking less costly repair parts can decrease the WRA's AWP time and hence reduce the number of WRAs needed to cover those waiting for parts.

A change from stocking no repair parts for a given WRA to stocking a few key parts can dramatically reduce depot TAT. Those first parts are very valuable. As stock levels increase, however, there comes a point at which adding more stock will have little effect on a WRA's AWP time.

Thus, the value of a part is not the unit price of the item. The value of a part is how much it contributes to shortening the repair time of the end item that uses it. This value is not static; it changes over time depending on the demand rates for the WRA that uses it and the stocks in the system.

Agenda

- **Methods for managing repair parts**
  - **Defining the value of parts**
  - **Stocking parts to minimize the value of the repair pipeline for a given investment**
  - **Computing the value of parts**
- **Building authorized stock levels**
- **Evaluating authorization policies**
- **Future directions**

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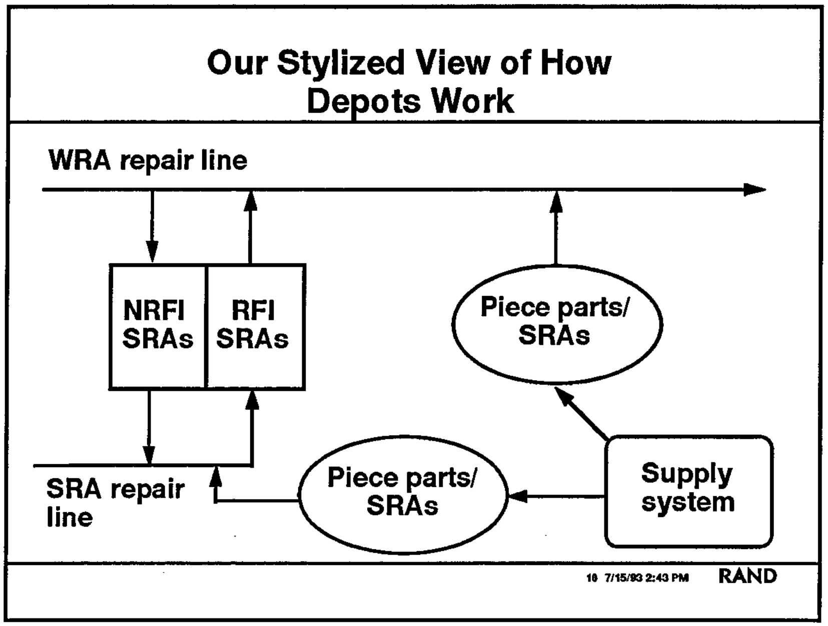
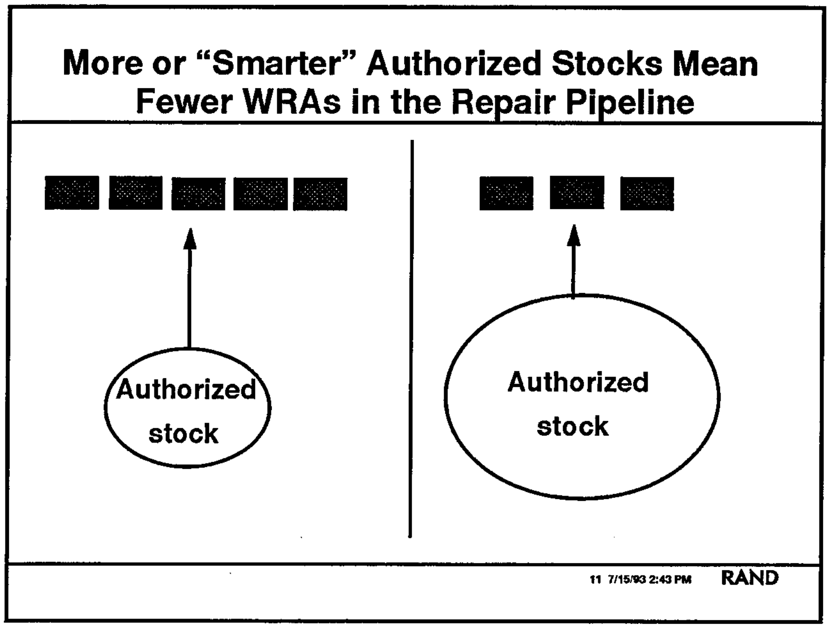
The briefing has four major sections. First we describe the methods for managing repair parts, after which we show how to use the methods to develop ordered lists of parts to be stocked at aviation depots. We then use simulation techniques to evaluate the methods and to assess whether biases are introduced because of the assumptions or the approximations. Finally, we present some suggestions for follow-on research.

In-depth information on these methods is developed in *Models and Algorithms for Repair Parts Investment and Management* (MR-314-A/USN, forthcoming). The details of the stockage policies and simulations are documented in *An Approach to Understanding the Relative Value of Parts* (MR-313-A/USN, forthcoming). The next section of this document begins with the general ideas behind our approach to defining the value of parts.

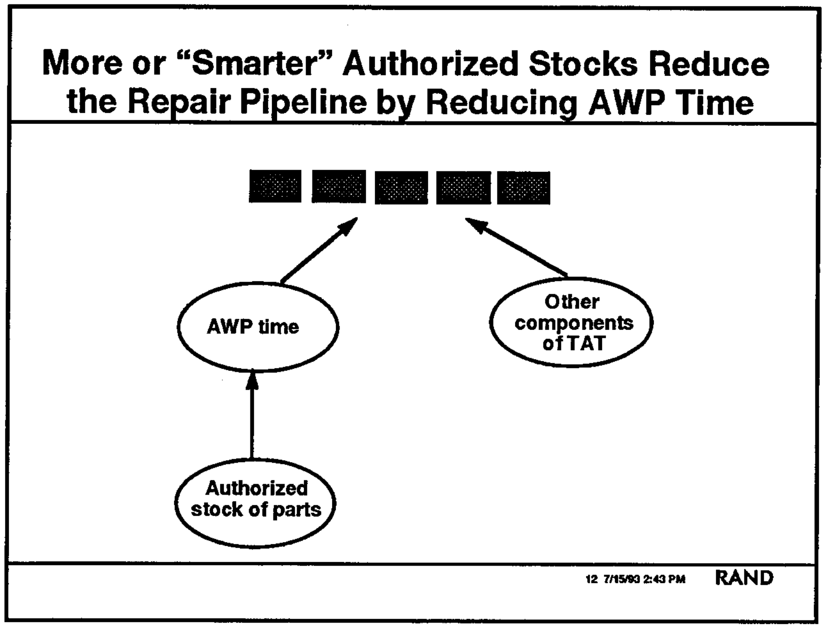


This chart describes our stylized picture of the repair processes in a depot. The goal of a depot is to get WRAs out the door quickly; in doing this, the depot is supported by supply activities and repair activities. Depots hold stocks of parts as buffers between the WRA repair line and suppliers. These authorized stocks are insurance against slow deliveries from the supply system. The main function of the stocks is to keep WRAs from waiting for parts.

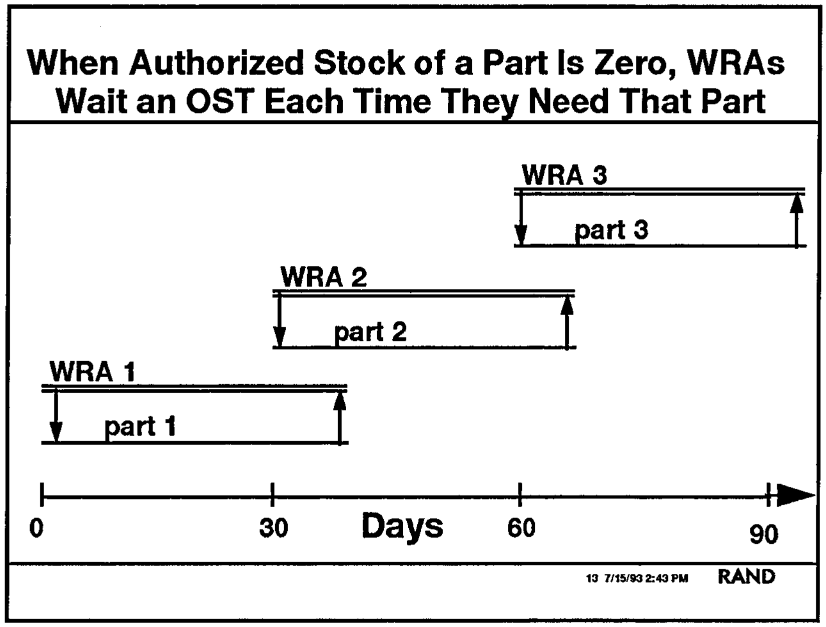
The stylized view of repair is as follows. A WRA comes into the WRA repair line. Broken (NRFI) SRAs are removed and replaced with good (RFI) SRAs—if they are available. Broken SRAs are sent to be repaired on the SRA repair line. (In reality, of course, there are rarely two distinct repair lines.) The supply system provides the piece parts needed for both SRA and WRA repair. The stock levels of piece parts and RFI SRAs affect how quickly the WRA is repaired.



The amount and types of parts held in the authorized stock buffers affect the number of WRAs in the repair pipeline. When the right parts are not available in sufficient quantities, expensive WRAs wait for parts, causing the number of WRAs in repair at any given time to increase. In this graphic and the one that follows, the boxes represent WRAs in the depot for repair.



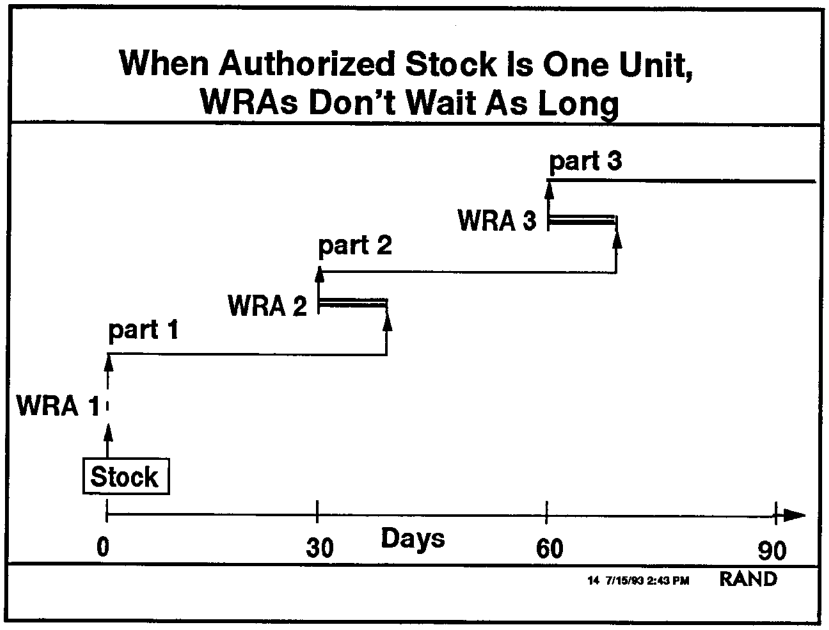
AWP time is one portion of the repair pipeline. We assume that authorized stocks of parts affect the size and length of the repair pipeline only through the AWP portion of the pipeline. Thus, our methods address the effect of stocks on AWP time.



This graphic shows how parts affect the size of the repair pipeline. Consider a hypothetical WRA that has only one part, which is required each time the WRA comes in for repair. When the depot has no units of the part in authorized stock, each WRA must wait a length of time equal to the OST before repair can be completed.

In this graphic, an NRFI WRA inducted at day 0 needs a part that is not in stock. The OST is 40 days, so the WRA waits 40 days for the part to arrive. Meanwhile, a second WRA arrives for repair at day 30. It also needs the repair part that must be ordered, and it also waits 40 days. In this example, with no parts in stock, one or two WRAs will always be in AWP status at the depot.

Forty days is a long OST. However, some inventory control points (ICPs) *average* that long for important classes of parts. (See page 31 for the average times needed for each ICP to provide AWG-9 radar parts.) This graphic on this page suggests the importance of reducing OST.



When the repair part has authorized stock of one unit, the situation changes. Here, the WRA arriving on day 0 is given the part in stock and is sent out the door. Meanwhile, a replacement is ordered for the part consumed by the repair of the first WRA. Since it takes 40 days for that part to arrive, the second WRA, which arrives on day 30, must wait for the part, but it only waits 10 days. Under these conditions, there are often no WRAs, and at most one WRA, in AWP status. Stocking one part has decreased the number of WRAs in the pipeline and has put working WRAs back into the system more quickly. Note that the same immediate effect could be achieved by shortening OST from 40 days to 10 days. However, more stock and shorter OST are generally not equivalent fixes.

The Reduction in AWP Is the Value of the Unit

- **A given set of stock levels yields AWP times and the value of the repair pipeline**
- **Add a unit to authorized stock; AWP times change, and so does the value of the repair pipeline**
- **That change defines the value of the unit added to authorized stock**
- **The value of a part changes over time as the inputs (cost, break rate, etc.) change**

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The two previous charts graphically show the difference stock levels make in both the amount of time a WRA waits for parts and how many WRAs are in repair. With this understanding, the value of a part can be defined.

A given set of stock levels yields particular AWP times for all of the WRAs and thus yields a value of the repair pipeline. If a unit of some part is added to authorized stock, the AWP time gets smaller for the WRAs that part goes on and, correspondingly, the value of the repair pipeline decreases. The decrease in the value of the repair pipeline is the value of that additional unit of stock.

This is a long-run, steady-state definition of the value of a part. It is based on the concept of buying a set of authorized stock, putting the stock at the depot, using the stock and replenishing it, and then evaluating the effects of the authorized stock on repair TAT over a long period of time. This definition of the value of a part, such as a circuit card on a radar antenna (a WRA), depends on the characteristics of the WRA—how often it breaks, what it costs—and on the characteristics of other parts that go on the WRA. Thus, the value of a part changes over time as the inputs change. As a consequence, depots must periodically review their stockage policies.

Agenda

- **Methods for managing repair parts**
  - –Defining the value of parts
  - → –Stocking parts to minimize the value of the repair pipeline for a given investment
  - –Computing the value of parts
- **Building authorized stock levels**
- **Evaluating authorization policies**
- **Future directions**

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Next we show how to use the value measure to stock parts so that the value of the repair pipeline is minimized for a given investment in repair parts.

We Use the Following Algorithm to Stock Parts

- **Step 1: Start with all authorized stock levels = 0**
- **Step 2: For each item compute**

$$\frac{\text{value of next unit}}{\text{unit price}} = \text{rate of return}$$

- **Step 3: Select the item with the highest rate of return and add a unit of it to authorized stock**
- **Step 4: Any money left? If so, go to step 2; if not, stop**

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This chart shows how we used value to build a stock position for a given amount of investment. We begin by assuming the depot has no authorized stock, so that each WRA inducted for repair must wait for all its parts. Then, for each part in a bill of material (BOM), we calculate the rate of return for stocking one more unit of that part. We then choose the part yielding the highest rate of return and add a unit of it to the list of authorized stock, continuing the process until all the money to be invested has been spent.

Steps 2 and 3 talk about evaluating and stocking the next unit of each item. It is not necessary to work with single units: any increment to stock can be evaluated. For cheap items, such as washers, or items with units per application (UPA) greater than one, it usually makes sense to work with increments greater than one. Step 4 talks about stopping the algorithm when a budget constraint is reached, but any of a number of criteria could be used to stop the algorithm. For example, stocking could continue until the average AWP time was acceptable or until the return reached some predetermined value, e.g., 2:1.

The Relevant Cost Measure Is the Sum of Unit Prices of Units in Authorized Stock

- **If the depot keeps zero authorized stock, it must buy the parts it uses on a job**
- **If the depot keeps some authorized stock, it must buy the same number of parts, but here the objective is to replenish stock**
- **Authorized stock is an investment, and reduction in pipeline value is the return on that investment**

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The algorithm on the preceding chart used unit price as the cost measure in the optimization. To see why, consider the following. If the depot has authorized stock levels of zero for all parts, it would need to buy from the supply system every part required for every repair job. If, instead, the depot has some authorized stock, it still must buy from the supply system every part required for every repair job, the only difference being that because it buys to replenish its stock, it buys the parts sooner than if it kept no authorized stock. The one-time purchase of parts up to authorized stock levels is an outlay made in addition to the cost of parts needed for jobs, which would be incurred whatever the authorized stock levels were. The cost of the inventory is determined by the depth of stockage of the various parts and by their unit prices; the return for buying that inventory is reduced AWP time. An efficient inventory is the set of authorized stock levels that makes AWP time (actually, the value of the repair pipeline) smallest for a given investment.

Thus, stocking parts can be viewed as an investment. The return on the investment in authorized stock is a reduction in the pipeline value, and the cost of that investment is the sum of the unit prices of the units in authorized stock.

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So far we have defined value and shown one way to use it, without showing how we compute it. We have made a particular set of assumptions to compute values of parts. Other assumptions are possible; ours reflect one way to balance complexity of calculation and realism of assumptions.

Some Details Underlying Our Computation of Value

- **We make specific assumptions regarding several areas:**
  - **When parts are demanded and needed**
  - **How depots replenish authorized stocks**
  - **How jobs arrive, OST varies, and SRA repair is handled**
- **A key formula (the tall-pole formula) approximates the expected time a WRA waits based on RFs and "get times" of the parts going on the WRA**

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To compute value, it is necessary to make some assumptions. For WRAs inducted into a depot for repair, we must specify when artisans know what parts are broken, and when those parts are needed (e.g., are all parts needed immediately?). We also need to specify how depot stocks are replenished, how WRA inductions and OST vary, and the characteristics of SRA repair.

In calculating the expected time a WRA waits for the parts it needs, we use one formula repeatedly: the tall-pole formula. This is an approximation of the actual expected AWP time. Later in this presentation, we show how close this approximation is to simulated values.

Computing AWP Time Requires Two Assumptions About Repair Part Demands

Assumptions

(1) As soon as the NRFI WRA is inducted, the parts needed to fix it are known

(2) Those parts are needed immediately, so any time spent waiting for them is AWP time

Consequences

- **The AWP clock starts on induction and runs until the last part shows up**
- **The resulting definition of AWP time is not consistent with current Navy terminology**
- **More consistency is possible but at a steep cost**

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To compute value, it is necessary to define and compute AWP time. This requires assumptions about when artisans know which parts are needed to repair a given WRA, and when those parts are needed. For example, artisans may know the necessary parts as soon as a WRA is inducted, but long repair processes may mean that some of those parts cannot actually be used for several days. We simplified by assuming that as soon as the NRFI WRA is inducted, the parts needed to repair it are known and needed immediately. Thus, any time spent waiting for the necessary parts is AWP time.

As a consequence of these assumptions, we start the AWP clock the moment the WRA is inducted and stop it when the last part arrives. We acknowledge that this is not the usual Navy definition of AWP time; it is more consistent with the definition of average customer wait (ACW) time. However, to be more consistent would require much more work and data, with unclear additional benefit. The current inefficiencies in the depot system lead us to believe that it would be unproductive to acquire data on job flow times or job scheduling, or to model the system as it exists in any greater detail than this model already does.

Computing AWP Time Requires an Assumption About Replenishment of Parts

- **We assume (S,S-k) ordering**
  - **In this briefing, we assume (S,S-1) ordering**

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AWP time is dependent on the replenishment policy followed by the depot. We assumed an (S,S-k) reorder policy. This means that the authorized stock level is S and the stock is replenished when k units have been consumed. For simplicity, the work presented in this briefing uses an (S,S-1) reorder policy: each time one unit of stock is used, a replacement part is ordered.

Computing Expected Wait [E(wait)] for Individual Parts Requires More Specific Assumptions

- We have formulas for sets of assumptions about three items that affect the computations:
  - Arrival of jobs
  - OST for parts ordered from the supply system
  - SRA repair time
- The sets of assumptions differ according to how much uncertainty they permit
- One assumption is common to all sets:

SRA repair time = repair process time + AWP time

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The related methodology report, *Models and Algorithms for Repair Parts Investment and Management* (MR-314-A/USN, forthcoming), provides formulas for sets of assumptions about three items: the arrival of jobs at the depot, the OST for parts that come from the supply system, and the length of time required to repair SRAs. The three sets of assumptions vary according to how much uncertainty they permit.

All three sets treat the time to repair an SRA as being equal to the repair process time plus the AWP time. The only portion of the SRA repair time affected by stocking parts at the depot is the AWP time.

Steps Involved in Computing the Value of (say) a Circuit Card on the Radar Antenna

- For each SRA on the antenna, compute E(wait) for the SRA
  - For each part, compute E(wait) for that part if repair of the SRA needs that part
  - Plug these and RFs of parts into the tall-pole formula
- Compute E(AWP) for the antenna
  - For each piece part going on the antenna, compute E(wait) if the antenna needs that part
  - Plug these, E(wait) for SRAs, and RFs of parts into the tall-pole formula
- Add a unit of the card to authorized stock, repeat the above, take the difference, and multiply by the unit cost and induction rate of the antenna

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With these assumptions, then, we can describe the steps in calculating the value of a specific part. The assumptions given on the three preceding charts permit computation of E(wait) for part i given that part i is needed. The tall-pole formula permits computation of the expected length of time a WRA or an SRA waits for parts, E(AWP). The tall-pole formula is used repeatedly in computing value, and without it our methods would be impractical. We discuss it on the next chart and give examples of its use later in the briefing.

E(AWP) Is Computed Using the Tall-Pole Formula

- **Assume an antenna has four parts**
- **Sort the parts in decreasing order of the time the antenna waits for them, if it needs them (table on left)**
- **Compute E(AWP) by the formula on the right**

part	wait	RF
1	40	.05
2	35	.1
3	25	.5
4	10	.01

$$
\begin{aligned}
E(AWP) &= 40 * .05 \\
&+ 35 * .95 * .1 \\
&+ 25 * .95 * .9 * .5 \\
&+ 10 * .95 * .9 * .5 * .01 \\
&= 16
\end{aligned}
$$

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For this illustration, assume a radar antenna has four parts, which are sorted in descending order of the time the antenna must wait for them if it needs them (as represented in the table on the left). Also assume for now that these waiting times are deterministic.

If an antenna needs part 1, it must wait 40 days for that part regardless of which other parts are needed—part 1 is the "tall pole" in the tent because it has the longest waiting time. The probability that part 1 will be needed is .05, the RF of part 1; so part 1's contribution to E(AWP) is 40 * .05—the first line in the formula.

Now if part 1 is not needed and part 2 is needed, then part 2 will be the tall pole, with a wait of 35 days. This case happens with probability .95 * .1, the first term being the probability that part 1 *will not* be needed, and the second being the probability that part 2 *will* be needed. Part 2's contribution to E(AWP) is 35 * .95 * .1—the second line in the formula.

If neither part 1 nor part 2 is needed, part 3 will be the tall pole, with a wait of 25 days. This case happens with probability .95 * .9 * .5, the probability that part 1 will not be needed times the probability that part 2 will not be needed times the probability that part 3 will be needed. Thus, part 3's contribution to E(AWP) is 25 * .95 * .9 * .5.

Finally, if only part 4 is needed, then its contribution to the expected AWP time is 10 times the probability that part 1, part 2, and part 3 will not be needed times the probability that part 4 will be needed. Thus, the last line in the formula is 10 * .95 * .9 * .5 * .01, and the E(AWP) for the radar antenna is 16 days.

Given this set of possible events and their respective probabilities of occurrence, the tall-pole formula computes the antenna's E(AWP) time. If the waiting times are deterministic, as we have assumed so far, the tall-pole formula is exact. If the waiting times are stochastic with means equal to the values in the table on the left, the tall-pole formula is an approximation because the stochastic process yielding the WRA's wait for parts is much more complicated. The complication arises because the parts required for the repair must first be determined stochastically, stochastic waiting times must then be determined for the needed parts, and the WRA's waiting time must then be determined as the maximum of the waiting times for parts. As the number of parts on the WRA grows, it becomes much more time-consuming to compute the expectation of this maximum. The tall-pole formula approximates the exact computation.

The tall-pole formula is central to our computation of value. Without it, our methods would be impractical. The quality and consequences of this approximation are discussed in the next section of the briefing and in Section 4 of *Models and Algorithms for Repair Parts Investment and Management* (MR-314-A/USN, forthcoming).

Agenda

- Methods for managing repair parts
- **[Building authorized stock levels]**
- Evaluating authorization policies
- Future directions

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We have outlined some methods for calculating the value of a part. Next we use these to build authorized stock levels. Remember that our objective is to minimize the value of the repair pipeline.

Two Steps in Building Authorized Stock Levels

For each of 11 SMICs:

- ➔ **Compile selected information**
- **Build a rank-ordered list of increments to authorized stock**
  - **Compute the value of each repair part based on current stockage levels**
  - **Select the part with the highest value**

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We now use the algorithms just described to build authorized stock levels for eleven different weapon systems, each of which is identified in the data by its SMIC (special material identification code). The two steps involved in building the authorized stock levels are compiling the information needed to compute the algorithms and using the output from the algorithms to build a rank-ordered list of parts to stock.

Compile Selected Information

- Types of information
  - Unit prices
  - Induction rates for WRAs
  - OSTs for repair parts
  - WRA and SRA BOMs
  - SRA processing times
- Data sources
  - Requisitions from NIMMS
  - ASO parts-level files

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This chart shows both the information needed and the data sources. Note that all the data used in these calculations are data the Navy routinely collects but does not compile in the way we did. The NIMMS data came from three depots—Jacksonville, Norfolk, and North Island. The price information came from ASO's IBMBX1 file.

We now walk though the data acquisition process using the AWG-9 radar on the F-14 as an example. The next three charts illustrate the steps in a spreadsheet-type format.

Get Induction Rates for WRAs (AWG-9 Radar)

WRA	Cost of WRA	#Jobs	IndRate
1. Transmitter	$236,040	148	.135
...			
...			
179. Antenna	303,050	1021	.932

Source: 1989–1991 NIMMS

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Our data for the induction rates for the AWG-9 radar were three years (1989–1991) of NIMMS data. These data showed that the AWG-9 had 179 WRAs repaired in those three years and that the procurement cost ranged from about $1,000 to $303,050. There were 148 transmitters repaired in the three-year period (1,095 days), giving an induction rate of .135 per day. The data documented 1,021 jobs for the antenna, yielding an induction rate of almost one antenna per day.

Calculate Order-and-Ship Times (AWG-9 ICPs)

ICP Code	ICP Name	Avg OST (Days)
1R	ASO consumable	22.6
7R	ASO repairable	40.0
. . .		
9G	DGSC	12.9
9J	Oklahoma City ALC	32.4
9K	Sacramento ALC	69.4
. . .		
9Z	DISC	25.0

Source: 1989–1991 NIMMS

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For each part needed to repair an AWG-9 WRA, we calculated the number of days that it took the supply system to produce the part. We did this by averaging customer wait times for requisitions made directly to the supply system (i.e., initiated in NIMMS by record type 11 or 12). To reduce random variation (some parts were infrequently ordered), we replaced the ACW times for each part by ACW times for all parts in the part's SMIC/ICP grouping. When a part came from the Naval Industrial Fund (NIF) store, it had a customer wait time of zero.

Note: These OSTs are specific to the AWG-9 radar. When we did the comparisons for all SMICs, we used different OSTs for each SMIC/ ICP combination.

Compile Bills of Material (AWG-9 Radar Transmitter)

	NIIN	Unit Price	Repl Factor	ICP Code
1.	000018836	$ 4	0.0068	9N
2.	000973633	300	0.1689	9N
3	001306794	19330	0.2838	7R
4.	001322907	705	0.1216	1R
5.	002246580	778	0.1351	1R
6.	004348939	113	0.1149	1R
7.	004383487	4000	0.1081	1R
8.	004707557	5	0.1149	9G
....				
384.	LLND90325	96	0.0068	1R
385.	LLND97069	47	0.0068	1R

Source: 1989-1991 NIMMS

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Using the NIMMS data, we complied a BOM for each WRA. This chart shows some of the 385 parts on the AWG-9 radar transmitter. Our BOMs included the NIIN (national item identification number), the unit price, an RF calculated from the data, and the ICP responsible for the part. Some of these parts were inexpensive and some were extremely costly. Some had RFs of one, meaning they were always replaced when the WRA was repaired, and some had very low RFs. Obviously, our BOMs only contain parts that were demanded during the three-year period covered by the data. Thus, if a part was never demanded during that period, it is not in our BOMs.

Reality of Using NIMMS Data

- Limitations
  - Past experience may not be predictive
  - Errors in BOMs
  - Many SRA jobs do not show up in NIMMS
  - No information on SRA processing times
- Implications
  - Better data needed
  - For now, treat SRAs like other repair parts

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The purpose of this chart is to caution the reader that there are many reasons to view the results of this research with caution. NIMMS data may not be predictive of the future; they document past experience. The induction rate of WRAs may change in the future because of changes in flying programs and the aging of the weapon systems. As the induction rates change and a different mix of parts is repaired, the value of individual parts will also change. We did not attempt to reconcile our BOMs from NIMMS with item managers, shop foremen, or illustrated parts breakdowns. Certainly, this step would be necessary in actual implementation of these methods. For reasons we do not completely understand, the NIMMS data contained few SRA repair jobs. Thus, in this analysis, we did not represent SRA repair and thus have treated SRAs like other repair parts. When better data are available, the methods can be used to include piece part support for the SRA repair pipeline.

Two Steps in Building Authorized Stock Levels

For each of 11 SMICs:

- Compile selected information
- ➔ Build a rank-ordered list of increments to authorized stock
  - Compute the value of each repair part based on current stockage levels
  - Select the part with the highest value

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We now demonstrate how to build the rank-ordered list of parts. This is done by repeatedly computing the value of each part, given the current stockage levels, and selecting the part with the highest value.

Compute E(AWP) Time via the Tall-Pole Approximation

4-NIIN AWG-9 Radar Transmitter

NIIN	Cost	RF	Stock Level	ICP Code	Get Time
001306794	19330	.28	0	7R	40.0
004348939	113	.11	0	1R	22.6
000973633	300	.17	0	9N	13.4
000047075	5	.11	0	9G	12.9

"Tall-Pole" Calculation

(.28*40) + (.72*.11*22.6) + (.72*.89*.17*13.4) + (.72*.89*.83*.11*12.9) = 15.2

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To illustrate the computations, we use a hypothetical example of a radar transmitter composed of only four parts. One part (001306794) is very expensive and one (000047075) is very inexpensive. Which part is the most *valuable?*

The next few charts fill in the spreadsheet until we can identify the "best" part. We begin with an authorized stock level of zero and calculate the average time the transmitter waits until all parts are available to accomplish the repair. The tall-pole calculation gives the answer—15.2 days. When the authorized stock is zero, the average get time comes from the table shown on page 31, which contains the average OST by ICP.

Add Expected AWP Time to Spreadsheet

4-NIIN AWG-9 Radar Transmitter

NIIN	Cost	RF	Stock Level	Get Time	Expected WRA Wait
001306794	19330	.28	0	40.0	15.2
004348939	113	.11	0	25.4	15.2
000973633	300	.17	0	13.6	15.2
000047075	5	.11	0	12.6	15.2

from tall-pole calculation

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The spreadsheet now has a new column—Expected WRA Wait—containing the number calculated on the previous chart. Thus, when there is no authorized stock and the RFs and get times are as found in the NIMMS data, it will take on the average 15.2 days to obtain the parts to repair this radar transmitter.

Effects of Adding One Unit of NIIN 001306794

4-NIIN AWG-9 Radar Transmitter

NIIN	Cost	RF	Stock Level	Get Time	E(Wait)	Get Time (Stock=1)	New E(Wait)	E(Wait) Reduction	Reduction per $
001306794	19330	.28	0	40.0	15.2	24.1	10.7	4.5	.000
004348939	113	.11	0	25.4	15.2				
000973633	300	.17	0	13.6	15.2				
000047075	5	.11	0	12.6	15.2				

$$\frac{(\mathrm{RF(part)} \times \mathrm{IndRate(WRA)})^{\mathrm{stock(part)}}}{(\mathrm{RF(part)} \times \mathrm{IndRate(WRA)} + 1/\mathrm{OST(part)})^{\mathrm{stock(part)}+1}}$$

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Adding one unit of a part to depot stock reduces the average get time for that part and yields a new E(wait) for the WRA. The spreadsheet has been expanded to include the new information. The formula to calculate the change in get time for NIIN 001306794 when adding one unit to authorized stock appears below the spreadsheet. It is a relatively simple formula, using only the RF for the part, the induction rate of the WRA, the OST for the part, and the stock position. The get time when one unit is aded is 24.1 days, compared to 40.0 days when no units are in stock. Using this new get time and the tall-pole formula, the new E(wait) time is 10.7 days: the reduction in E(wait) time from adding a unit of this NIIN to authorized stock is thus 4.5 days. Dividing 4.5 by the price of the part ($19,330) yields the reduction in waiting time per dollar spent. In this case, because the part is so expensive, the reduction per dollar is zero to three decimal places.

Repeat Last Step to Identify "Best" Part

4-NIIN AWG-9 Radar Transmitter

NIIN	Cost	RF	Stock Level	Get Time	E(Wait)	Get Time (Stock=1)	New E(Wait)	E(Wait) Reduction	Reduction per $
001306794	19330	.28	0	40.0	15.2	24.1	10.7	4.5	.000
004348939	113	.11	0	25.4	15.2	05.7	14.0	1.2	.010
000973633	300	.17	0	13.6	15.2	03.2	14.2	1.0	.003
000047075	5	.11	0	12.6	15.2	02.1	14.6	0.6	.127

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Now we fill out the other rows in the spreadsheet, using the formula on the preceding chart to calculate the new get time when one part is stocked and the tall-pole formula to obtain the new E(wait) time. Subtracting the two wait times yields the E(wait) reduction. Note the last column, which is the E(wait) reduction divided by the price of the part. NIIN 000047075 yields the largest reduction (.127) per dollar spent. As a result, it is the first part that we would stock for this WRA.

Calculate Pipeline Reduction for Best Part

4-NIIN AWG-9 Radar Transmitter

NIIN	Cost	RF	Stock Level	Get Time	E(Wait)	Get Time (Stock=1)	New E(Wait)	E(Wait) Reduction	Reduction per $	Pipeline Reduction per $
001306794	19330	.28	0	40.0	15.2	24.1	10.7	4.5	.000	
004348939	113	.11	0	25.4	15.2	05.7	14.0	1.2	.010	
000973633	300	.17	0	13.6	15.2	03.2	14.2	1.0	.003	
000047075	5	.11	0	12.6	15.2	02.1	14.6	0.6	.127	$4,037

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The final computation is the pipeline reduction per dollar spent. For the best part—NIIN 000047075—this reduction is $4,037. This number is the product of the cost of the WRA ($236,040), the induction rate of the WRA (.135 per day), and the E(wait) reduction per dollar spent (.127 days per dollar). The cost and induction rate of the radar transmitter were shown in the chart on page 30.

Summary of Where We Are

- This is the result for a four-part AWG-9 transmitter
- We did the calculation for a real AWG-9 transmitter
- We did the calculation for 178 other WRAs on the AWG-9
- We arrayed the best parts in a list

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The spreadsheet example stocked the first unit for a four-part radar transmitter. We actually did the calculation for the real AWG-9 transmitter and for all the other 178 WRAs on the AWG-9. Starting with a stock position of zero, we asked, "What is the first part that should be stocked?"

Select the Most Valuable Part Across All WRAs (AWG-9 Radar)

Values of Best NIINs, by WRA (AWG-9 Radar)

WRA	WRA Cost	Ind Rate	Best NIIN	NIIN Cost	E(Wait) Reduction per $	Pipeline Reduct per $
1. NTT1	236040	.14	008457769	$1	0.04	$1,277
2. LV16	47620	.24	003105304	$1	0.35	$4,002
3. QE22	142100	.10	000095709	$1	0.44	$6,303
4. KTW6	303050	.93	009940720	$1	0.07	$18,726 ←
5. P6B3	178350	.19	000079879	$1	0.14	$4,709
6. KXF5	121740	.03	000905194	$1	1.25	$4,572
...						
179. QE22	142100	.10	002920580	$1	0.31	$4,435

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When the previous calculations were done for each WRA on the AWG-9 radar, the algorithm identified NIIN 009940720 on the radar antenna as the highest valued part. Stated another way, stocking this part will save more pipeline value per dollar of stock than will stocking any other part. Notice that the part only costs $1. Thus, the intuition that says " buy inexpensive parts first" was borne out in the first calculation.

The last column, pipeline reduction per $, is the product of the WRA cost, the induction rate, and the E(wait) reduction per dollar. However, the $18,726 value (highlighted by the arrow) should be viewed conservatively. Whenever the stock position is zero, the first few units stocked will appear to have unrealistically large savings. It is more appropriate to look at the marginal savings to the system when there are more parts in authorized stock. We show this on page 43.

Summary of Where We Are

- This gets us one part for the entire AWG-9
- We did this n times to get an authorized list of n parts for the AWG-9

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The next steps are to repeat the calculations n times to obtain the authorized list of n parts.

Ranked Increments to Authorized Stock (AWG-9 Radar)

First 3000 Acquisitions for AWG-9 Radar

	WRA	NIIN	Cost	E(Wait) Reduct	Pipeline Reduct per $
1.	KTW6	009940720	$1	0.1	$18,726
2.	KTW6	000035339	$1	0.1	$1,760
3.	KTW6	000695291	$1	0.0	$1,317
	...				
999.	J651	LLL105643	$2	8.7	$90
1000.	N130	004649293	$13	2.5	$90
1001.	KTW6	009352587	$5	0.0	$89
	...				
2998.	NTT1	010076822	$34	0.0	$8
2999.	NTT1	002246580	$778	0.2	$8
3000.	NTT1	001322907	$705	0.2	$9

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This list shows a ranked (most valuable to least valuable) list of parts on the AWG-9 radar. It is the result of applying the computations 3,000 times. As noted before, the first three units stocked are all $1 parts with large returns on investment. By the time there are 998 parts in stock, moderately priced parts ($2–13) are being stocked, and the values in the last column have become more reasonable (e.g., buying a $5 part translates into a pipeline reduction per dollar spent of $89). The last few parts are much more costly, over $700, and yield a modest $8–9 pipeline reduction per dollar spent.

Summary of Authorized Stock Lists

	SMIC	Description	Actual #Jobs	#Parts Required
1.	BE	e2/c2 electronic a/c	4,526	4,000
2.	BP	p3 patrol aircraft	7,915	5,000
3.	CY	awg-9 radar	3,408	3,000
4.	DH	h3 helicopter	1,556	2,000
5.	DQ	t56 engine	6,048	5,000
6.	EQ	t58 engine	9,055	4,000
7.	FQ	t64 engine	3,591	3,000
8.	MH	h46 helicopter	2,524	3,000
9.	PQ	tf30 engine	6,515	4,000
10.	RA	a6e attack aircraft	3,466	4,000
11.	TN	f404 jet engine	5,158	4,000
		Total	53,762	41,000

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For each of the eleven SMICs in our data, we computed rank-ordered lists of parts like the ones we constructed for the AWG-9 radar. The column #Parts Required is the number of units of authorized stock we put on the rank-ordered list for each SMIC; this gives a sense of the size of the problem we dealt with. The column Actual #Jobs is the total number of jobs in the NIMMS data for that particular SMIC.

Agenda

- Methods for managing repair parts
- Building authorized stock levels
- **Evaluating authorization policies**
- Future directions

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Having shown how to build rank-ordered lists of parts, we now wish to evaluate how effective it might be to stock those parts. That is, How much depot throughput time would be saved if these parts were readily available to artisans?

We would like to be able to tell the Navy, "Here is the payoff you will get from setting authorized stock levels according to our value method." Unfortunately, we cannot make this statement because we do not know current authorized stock levels. We show some comparisons to assess whether specific aspects of our methods introduce errors or inefficiency.

Evaluate Authorization Policies

- Simulation ideas
- "Nonparametric" and "parametric" simulations
- Baseline and treatment cases
- Results for 11 SMICs (SMIC and WRA level)

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To evaluate the method of stocking parts according to value, we performed two different simulation exercises—one "nonparametric" and one "parametric." Because we did not know the authorized stock levels at the depots, we had to impute some authorized stock levels for each SMIC. We called this the baseline case. Then, we added 1,000 units to these baseline authorized stock levels to create the treatment case. We summarized the results at both the SMIC and WRA levels.

Simulation Ideas

For each day

- **Induct WRA jobs at historical rates**
- **Simulate parts requisitions**
- **Simulate requisition fills**
  - **If authorized and in stock, zero days**
  - **Otherwise, look to due-in pipeline**
  - **Otherwise, order from supply system**
- **Order authorized stock early: (S,S-1)**

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In both the nonparametric and parametric simulations, we simulated WRA repair inductions along with repair and parts requisitions and receipts. WRAs were inducted at historical rates, as calculated from three years of NIMMS data. Then, requisitions for parts were simulated using parameters calculated from the NIMMS data. The times to fill the requisitions were also simulated. If the part was in stock, the wait was zero. If not, the simulation looked to the due-in pipeline to see whether the part had been ordered earlier. If not there either, the part was ordered from the supply system. All replenishment was done according to an (S,S-1) reorder scheme.

Nonparametric and Parametric Simulations

- **Nonparametric uses actual NIMMS data wherever it can**
  - **Actual demands**
  - **Actual fill times if requisition went to supply system; random draw otherwise**
- **Parametric makes random draws from probability distributions**
  - **Binomial demands**
  - **Negative exponential fill times**

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The distinction between the two types of simulations lies in how the demands and requisition fill times were simulated. The nonparametric simulation tried to mimic the actual job streams found in the data by using the dates the jobs started, the parts requisitioned for those jobs, and the actual get times for orders that went to the supply system. The parametric simulation used the data to estimate parameters of probability distributions and then made random draws from those distributions to calculate the demands and the time to fill those demands.

If the results from the simulations were found to be close to those computed as part of our stockage methods, we knew we could have some confidence that our methods were not introducing inaccuracies because of either the mathematical approximations (specifically the tall-pole formula) or the assumptions about WRA inductions and OST. Of course, this is only a simulation test of the methodology. If successful, it argues for a trial at a depot, not a full-scale implementation.

Baseline Case: Reproduce Observed AWP Times Within SMICs

	SMIC	Description	Actual #Jobs	Actual Avg AWP	#Parts, imputed stock	Avg AWP, imputed stock*
1.	BE	e2/c2 electronic a/c	4,526	35.8	2,328	34.6
2.	BP	p3 patrol aircraft	7,915	23.3	3,865	22.6
3.	CY	awg-9 radar	3,408	29.7	1,424	31.0
4.	DH	h3 helicopter	1,556	33.6	491	34.3
5.	DQ	t56 engine	6,048	11.3	3,347	10.6
6.	EQ	t58 engine	9,055	16.4	2,592	14.9
7.	FQ	t64 engine	3,591	22.0	1,971	16.4
8.	MH	h46 helicopter	2,524	25.3	1,421	25.7
9.	PQ	tf30 engine	6,515	13.1	2,914	12.8
10.	RA	a6e attack aircraft	3,466	18.4	2,409	17.1
11.	TN	f404 jet engine	5,158	32.8	2,353	33.2
		Total	53,762	21.9	25,115	21.0

*computed using nonparametric simulation

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As noted, we did not have the depots' actual authorized stock levels, so we constructed a baseline list of stocks as a substitute. This table summarizes the results of the nonparametric simulation used to establish the baseline authorized stock levels at the depot.

The first three data columns were shown before; the fourth column is the actual average time the WRAs in each of the eleven SMICs spent waiting for parts. To obtain our baseline case, we simulated the number of parts the depot would have to stock to bring the average waiting time "close" to the actual time in the NIMMS data. For example, the actual AWP time for the AWG-9 radar was 29.7 days; if the first 1,424 units identified in our previous computations were stocked, the average AWP time, from the nonparametric simulation, would be 31.0 days.

Baseline and Treatment Cases

- **Baseline imputes current authorized stock at depot**
- **Treatment authorizes 1,000 additional parts within each SMIC**

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The baseline list of stocks yields wait times close to the wait times experienced at the depot. The treatment case simply authorizes 1,000 more units of authorized stock for each SMIC. In the case of the AWG-9 radar, the baseline stock level was 1,424 units and the treatment case was 2,424 units. How beneficial are the additional 1,000 units?

We are not suggesting that the Navy consider, as a policy, adding 1,000 units of additional items to their authorized stock. However, such a computation is useful for our current purpose, which is to evaluate whether our methods introduce systematic biases. It is useful because adding 1,000 increments to stock for each SMIC ensures that we will see a wide range of returns on investments (ROIs), at the SMIC level as well as the WRA level, and then we can see whether the tall-pole tracks the simulations across this wide range.

Nonparametric Simulation and Tall-Pole ROIs Look About the Same

Value and Cost Summaries: Nonparametric Simulation

SMIC	#Parts Imputed Stock	$1,000 Additional Parts Costs	Simulated Waits Base	Simulated Waits Treat	Pipeline Reduct	Pipeline Reduction per $ Simulation	Pipeline Reduction per $ Tall-Pole
CY	1,424	$235,976	31.0	23.9	$4,963,814	21.0	17.9
DH	491	$72,404	34.3	20.7	$673,788	09.3	09.7
BP	3,865	$248,048	22.6	19.2	$1,526,312	06.2	05.3
BE	2,328	$167,329	34.6	26.9	$937,323	05.6	03.8
FQ	1,971	$185,456	16.4	09.3	$961,268	05.2	02.6
PQ	2,914	$292,366	12.8	09.5	$1,221,643	04.2	02.5
TN	2,353	$347,446	33.2	23.5	$1,304,606	03.8	03.4
RA	2,409	$183,992	17.1	12.2	$632,374	03.4	03.1
EQ	2,592	$174,445	14.9	11.9	$525,488	03.0	02.0
MH	1,421	$524,286	25.7	18.7	$708,191	01.4	01.2
DQ	3,347	$194,547	10.6	07.4	$150,799	00.8	00.5
Total	25,115	$2,626,295	21.0	15.7	$13,605,606	05.2	04.2

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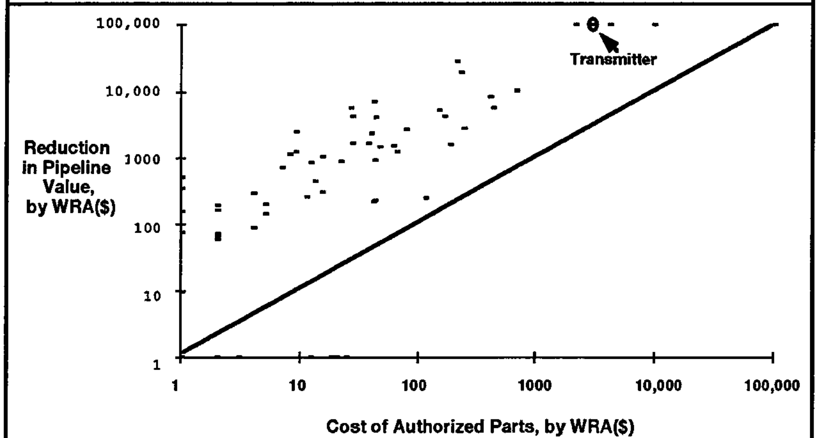
This table answers the question on the previous page. For the AWG-9 radar, the answer is that for each dollar spent on authorized stocks above the baseline, the repair pipeline was reduced by $21 in the simulation. The tall-pole computation predicted $17.9. The last two columns of the table tell us that the tall-pole did a good job of predicting which weapon systems would benefit from the additional stocking of parts and which would not. For the last two SMICs, MH (H-46 helicopter) and DQ (T-56 engine), both the simulation and the tall-pole showed that there was no benefit to placing stocks at the depot. All the other SMICs showed reasonable returns from this stocking strategy.

In the nonparametric simulation for all eleven SMICs, a total investment of $2.6 million beyond the baseline produced a pipeline savings of $13.6 million, and the average time the WRAs spent waiting for parts dropped from 21 days to 15.7 days in the simulation.

Tall-Pole Picks Mostly High-Return WRAs in High-Return SMIC CY (AWG-9 Radar)



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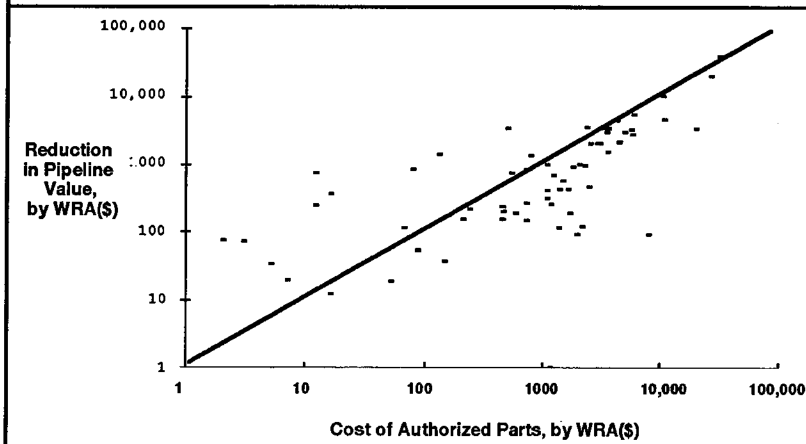
This graph shows why the AWG-9 radar produced the highest pipeline reduction per dollar spent. When the cost of the parts to repair a WRA is plotted against the reduction in pipeline value for that WRA, almost all the points are above the 45-degree line, which means that the reduction in pipeline value is greater than the cost of investment in parts. For example, for the transmitter, whose authorized stock cost a total of $2,936, the reduction in pipeline value was $143,564. Note the logarithmic scale on both axes, and that reductions in pipeline value in excess of $100,000 are plotted at the top of the scale.

Tall-Pole Picks Many Low-Return WRAs in Low-Return SMIC DQ (T-56 Engine)



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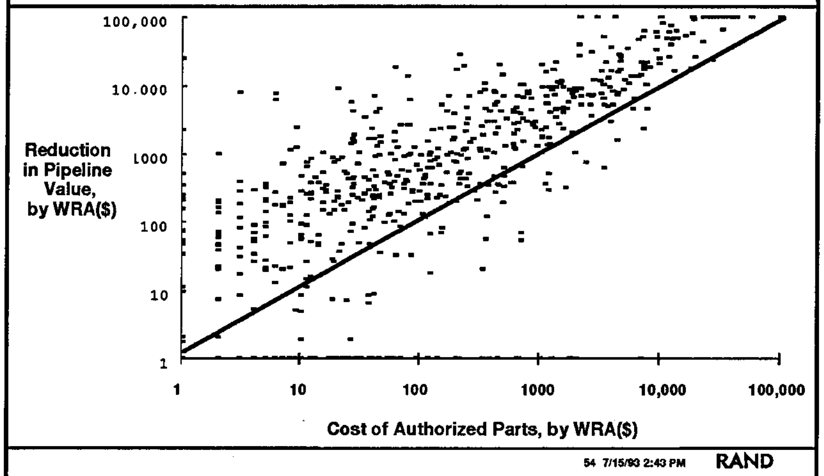
This is the analogous plot for the T-56 engine, which the tall-pole calculation predicted would not be a good candidate for investment in parts. The large number of points below the 45-degree line (the line is where the cost of parts equals the reduction in pipeline value) shows that many parts cost more than the pipeline value they save.

More analysis is needed to understand why the authorized stock levels produced by the tall-pole computation did not result in a reduction in the pipeline value. There is a point for each weapon system at which additional stock will have little marginal return. In the case of the T-56 engine, this point was reached before all 1,000 additional items were chosen. The baseline stock was already producing small AWP times; thus, the marginal return of purchasing additional stock was small.

The formula on page 37 suggests that the payoff to additional stocking will be low when (1) RFs are small, (2) WRA induction rates are low, or (3) OST is short. For the T-56 engine, the most likely reasons for small marginal returns are small RFs and low induction rates.

Tall-Pole Picks Mostly High-Return WRAs in High-Return SMICs



This graph shows all the WRAs in the nine high-return SMICs (i.e., excluding the T-56 engine and H-46 helicopter WRAs). Most of the points lie above the 45-degree line, indicating that the pipeline reductions shown on page 51 are not attributable to a big gain for one WRA, but are instead the result of stocking many WRAs, each of which contributes to a reduction in throughput. In these simulations, less than 1 percent of the parts purchased were not used (they are represented by the dots on the horizontal axis). The total unit price of these parts is $17,000.

Pipeline Value Is About 20 Percent Less for Baseline Versus Current Stock

Authorization Levels	Average AWP (days)	Cost of Parts ($ millions)	Pipeline Value ($ millions)
Zero	36.4	$ 0	$86.7
Current	21.9	???	54.9
Baseline	21.0	2.2	43.8
Treatment	15.7	4.9	30.2

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This chart summarizes the results. For the case of no authorized stocks, our nonparametric simulation has WRAs spending an average of 36 days waiting for parts (using our definition of AWP time). This means that $86.7 million worth of WRAs are in the repair pipeline in a nonworking status. Using the NIMMS data, we calculated that WRAs actually spent an average of 21.9 days waiting for parts. Since we do not know the current authorized stock levels, we do not know the investment in parts that it took to achieve this average AWP time, but the pipeline value is $54.9 million.

Recall that the baseline authorized stock levels were calculated so that repair times were close to the actual times seen in the data. These parts were chosen to minimize the pipeline value. Using these baseline stocks, the pipeline value decreases to $43.8 million, from $54.9 million, which is approximately a 20 percent reduction.

The treatment case added 1,000 parts to the baseline case for each SMIC, reducing AWP time to 15.7 days for a total cost of $4.9 million. These parts further reduced the pipeline value to $30.2 million.

Final Note: ROIs Are the Same for Nonparametric and Parametric Simulations

Returns on Investment for the Last 1,000 Parts

SMIC	Nonparametric Simulation	Parametric Simulation
CY	21.0	24.6
DH	9.3	14.2
BP	6.2	8.5
BE	5.6	5.0
TN	3.8	4.1
RA	3.4	3.7
FQ	5.2	2.4
PQ	4.2	3.1
EQ	3.0	2.6
MH	1.4	1.1
DQ	0.8	0.3
Total	5.2	5.5

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We do not show the details of the parametric simulation here, but we note that the ROI for the last 1,000 units in both the nonparametric and parametric simulations are similar. Both simulations show that the AWG-9 radar (CY) would benefit most from stocking parts using the tall-pole computations, and that the T-56 engine (DQ) would not benefit from doing so.

Summary

- We have some methods
  - Mathematics of E(wait) for repair parts
  - Tall-pole computation
  - Way of tying these together to produce lists of parts
- Simulations suggest that methods can
  - Produce good ranked lists
  - Identify high-return and low-return investments
- Recommendation: try them out on a small scale

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In summary, we have shown two mathematical formulas—one for calculating the expected time a WRA will wait for parts (tall-pole formula), and one for calculating the new get time when the stock is increased by one unit (see chart on page 37). We have used these formulas to produce lists of parts to stock at the depots.

Our simulations suggest that stocking parts according to these lists has the potential to reduce depot throughput times. Furthermore, the tall-pole calculation can identify which weapon systems it would make sense to stock parts for and which it would not.

We feel that the next step is a small-scale depot experiment: put a stock of parts at a depot and see if doing so actually leads to shortened throughput times.

Agenda

- Methods for managing repair parts
- Building authorized stock levels
- Evaluating authorization policies
- **Future directions**

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This final section of the briefing discusses other uses for the value-of-parts measure and proposes a depot demonstration for implementation of these stockage concepts.

How We Have Used Value of Parts

- **To demonstrate how value can be used to construct authorized lists of parts to be stocked at depots**
- **To assess the marginal returns from incrementing authorized stocks**

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Thus far we have used the value of a part to (1) build lists of parts to be stocked at depots and (2) evaluate the marginal returns from incrementing the current authorized stocks. What other possible uses are there for this value-of-parts measure?

Potential Uses of Value of Parts

- Help NAVSUP build a NADEPCAL
- Evaluate current reorder rules for existing stocks
- Evaluate how reorder rules should change as the external environment changes
- Trade off investments in parts against investments in other segments of the repair pipeline
- As a "bottleneck analyzer" as the system shrinks
  - To identify the problematic parts
  - To evaluate different ways to solve problems

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Should the Navy decide that it would like to stock parts at depots the way it stocks parts on deploying carriers in AVCALs, this methodology could serve as a starting point for building those stocks. The Navy has called this idea a NADEPCAL.

Value of parts could also be used to evaluate current reorder rules for existing stocks and how those rules should change as weapon systems age, the force is drawn down, depot repair procedures change, etc.

The calculations can also be used to balance investment strategies between spending money on parts and spending it on other segments of the repair pipeline. Additionally, they identify parts that are problematic or may become problematic during force reductions.

What Comes Next?

- Two reports
  - Detailed documentation on the information covered in this briefing
  - Mathematical backup documentation
- No further paper tests—they would add no information
- Possible further development, which would require testing in a service depot (active partnership with service personnel is essential)

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Two additional reports document this work. *An Approach to Understanding the Relative Value of Parts* (MR-313-A/USN, forthcoming) is a much more detailed discussion of the topics covered in this briefing. It goes into more depth on the methods, including the underlying motivation, and describes the data, analytical findings, and simulations that someone familiar with military logistics would need to replicate the work presented herein. It also details the proposed depot demonstration. *Models and Algorithms for Repair Parts Investment and Management* (MR-314-A/USN, forthcoming) provides the mathematical underpinnings of these methods and is intended for a technical audience.

We believe that further simulation testing of these methods would be of little value. The appropriate next step is to work with service personnel to develop a test at a depot.

We recognize that establishing authorized stock at a depot is but one piece in a much larger problem of increasing depot responsiveness. Experiences in the private sector show that changes in both policy and processes are necessary to achieve order-of-magnitude improvements in remanufacturing operations. In addition to setting authorized stock levels for the depots, the Navy must give attention to improving OST, RFs, demand rates, process times, maintainability, contracting, and the like.

MR-311-A/USN