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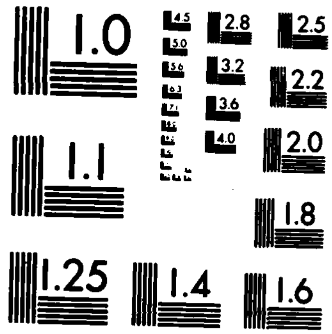

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NAVAL POSTGRADUATE SCHOOL
Monterey, California

THESIS

AN ANALYSIS OF THE ATLANTIC FLEET
AFS PHASED MAINTENANCE PROGRAM

by

Steven Charles Rowland

March 1984

Thesis Advisor: D. C. Boger

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An Analysis of the Atlantic Fleet AFS Phased Maintenance Program

by

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Submitted in partial fulfillment of the requirements for the degree of

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The Combat Stores Ship (AFS) Phased Maintenance Program was authorized in 1979 as a five year test effort to stabilize deployment patterns for Atlantic Fleet AFSs and to test a progressive maintenance policy similar to the one used by the Military Sealift Command.

This study analyzes the costs and benefits of the AFS Phased Maintenance Program (AFSPMP) relative to the conventional maintenance policy that was in use prior to the AFSPMP. The depot and intermediate level maintenance manday and dollar costs are estimated for four alternative maintenance policies to aid in determining how well the AFSPMP is performing with regard to costs. The benefit analysis presents several quantitative and qualitative aspects of the AFSPMP and conclusions are drawn concerning the cost-effectiveness of the AFSPMP as compared to the conventional policy. Conclusions concerning the expansion of this program to other classes of ships are also presented, along with recommendations for further research in this area.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

I. INTRODUCTION

A. BACKGROUND

The Navy spends billions of dollars each year maintaining its fleet of surface ships. More than fifty percent of these funds is spent in overhauling them. During recent years ship overhaul costs have risen dramatically making it difficult for budgeteers to fund them adequately. The high cost of maintenance has become a major concern to the Navy, resulting in attempts to find maintenance strategies that are more cost-effective.

The Navy ship overhaul problem is an extremely complicated optimization problem that has not yet been solved. The nature of the problem is to find the most cost-effective method for scheduling and executing the depot level maintenance of Navy ships. The problem is necessarily very complex and presently the Navy is severely limited in its ability to reliably predict the consequences of alternative maintenance policies in terms of costs, ship availability, and material condition. Computer and analytical models have been generated, but most of them focus on subsets of the general problem in that they do not consider all of the variables.

There are three basic levels of Navy ship maintenance. At the lowest level, the ship's crew performs organizational maintenance; intermediate maintenance is accomplished primarily by Navy personnel in tenders, repair ships, or an equivalent shore Intermediate Maintenance Activity (IMA); and depot maintenance is accomplished by public and private facilities, primarily shipyards. Depot maintenance can be subdivided into scheduled Regular Overhauls (ROHs) or Selected Restricted Availabilities (SRAs) and unscheduled interoverhaul Restricted Availabilities (RAVs) or Technical Availabilities (TAVs). An RAV requires the presence of the ship at the repair facility and renders a ship incapable of performing its mission. A TAV does not require the ship to be present and does not affect the ship's ability to perform its mission [Ref. 1: pp. A-62, A-73]. Better management of these three levels of maintenance activity could potentially result in enormous savings to the Department of Defense and allow these funds to be used elsewhere. The Navy's basic maintenance strategy for support ships in the past has been a policy of periodic lengthy regular overhauls with a considerable amount of interoverhaul maintenance being performed by ship's crew and intermediate maintenance facilities. This will be referred to as the conventional maintenance policy.

For several years the Navy's maintenance policies have been criticized by the Congress, General Accounting Office, and other government activities. Some of this criticism started as a result of work done in the early 1970's by Cooper and Company. In 1974, comparisons of different maintenance policies and approaches revealed that the costs of maintaining a fleet oiler (AO) were far greater than the corresponding costs for the Military Sealift Command (MSC)[1] tankers/fleet oilers and enormously greater than the costs incurred by companies maintaining commercial tankers [Ref. 2: p. 10]. This indicates that the Navy might be able to reduce some of its maintenance costs through utilization of a maintenance policy similar to that used by MSC or commercial organizations.

The Navy has taken many steps to increase ship overhaul effectiveness. Most of these have been relatively minor changes in various aspects of overhaul policies--contracting, management practices, etcetera. In response to outside pressure and the specific problems encountered by the three combat stores ships (AFS-1 MARS class) assigned to the Atlantic Fleet, a major change in maintenance policy was devised with the hope that, if successful, it could be applied to other classes of ships. In 1979 the Chief of Naval Operations (CNO) authorized the AFS Phased Maintenance Program (AFSPMP) as a pilot effort with the Atlantic Fleet AFSs in an attempt to stabilize ship

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[1] The Military Sealift Command is a Navy command with fleet status and is one of three Transportation Operating Agencies established by direction of the Department of Defense [Ref. 3: p. II-6].

schedules and test a maintenance plan similar to that employed by MSC. A direct comparison of the two maintenance philosophies will be presented in Chapter V.

B. STATEMENT OF PROBLEM

The CNO authorized the AFS Phased Maintenance Program in 1979 as a five year test effort to: (1) modify the AFS overhaul cycle to minimize the duration of depot level maintenance periods to facilitate keeping one of three ships forward deployed at all times and (2) test a maintenance plan similar to that employed by the Military Sealift Command and commercial shipowners to determine possible benefits to the Navy [Ref. 4: p. 1]. The actual five year test commenced in 1981. Early indications are that the program has been successful in meeting its goals. The apparent success of this program led to a decision to put the Pacific Fleet AFSs into phased maintenance and, recently, the CNO authorized phased maintenance for reserve FF-1052 class frigates, additional classes of auxiliary ships, and some classes of amphibious ships. All of this is based on a very limited test of the AFSPMP. The three test AFSs have completed seven of their phased maintenance SRAs and have five more to go. Projections of total costs may therefore be inaccurate due to some unforeseen cause. In addition, the three program evaluations conducted thus far have concentrated on manday costs. While there are several good reasons for measuring cost in terms of mandays of work expended, it would have been useful for the program evaluations to address dollar costs in more detail. A stabilization or even a reduction in the total number of mandays expended in maintaining an AFS may or may not correspond to a reduction in the required dollar budget level. Another potentially significant problem is the application of the results, based solely on three AFSs, to other classes of ships.

C. OBJECTIVES AND METHODOLOGY OF THE ANALYSIS

The primary objective of the analysis will be to determine if the AFS Phased Maintenance Program has been successful in meeting its goals and if it is a cost-effective alternative to the conventional maintenance of AFSs.

In developing the analysis of the program this study will concentrate on the total depot and intermediate level maintenance costs for an Atlantic Fleet AFS for a five year operating cycle. Four major cost estimates will be made to aid in evaluating the performance of the phased maintenance program. These cost estimates will be made for the following alternative policies:

(1) FY 75-79 Conventional Maintenance Policy,

(2) FY 81-85 Conventional Maintenance Policy,

(3) FY 81-85 Phased Maintenance Policy, and

(4) FY 81-85 MSC Maintenance Policy.

The manday and dollar cost estimates for the first policy will be used as a baseline and represent the conventional maintenance costs over a five year cycle prior to phased maintenance. The second set of estimates will be a projection of the cost of conventional maintenance, as if the AFSs had not entered phased maintenance. It assumes there is a moderate amount of cost growth from one cycle to the next. The estimates for the third policy will be projections of the cycle manday and dollar costs of maintaining an AFS under the AFSPMP. Finally, the fourth will be an estimate of the dollar costs MSC would incur, if an AFS was transferred to it. In addition to the point estimates, confidence intervals for the manday and dollar costs will be constructed whenever possible.

This study will focus on manday and dollar costs, ship availability, and Casualty Report (CASREP) data in quantitatively analyzing the benefits of the program. Several nonquantifiable aspects of the program will also be addressed. These include schedule stability, material condition, training, and the port engineer concept. The sensitivity of the total costs to the intermediate maintenance costs and the scheduled and unscheduled depot level costs will also be discussed.

A secondary objective of the analysis will be to qualitatively investigate the advisability of the expansion of the phased maintenance program to other auxiliary, amphibious, and combatant ships, based on the results of the AFSPMP. The CNO has already authorized phased maintenance for some ship classes other than AFS's, but no decisions have been made concerning major combatants.

D. CONTENTS

The following chapter of this thesis will briefly describe the evolution of the conventional maintenance philosophy. Chapter III will briefly review the applicable results of several reports that indicate our present maintenance policy for support ships may not be optimal. *The reports are:* SOAMS Project: A Study Of Ship Overhaul and Maintenance, by Cooper and Company; A Comparison of Manning Options for the AO-177 Class Fleet Oiler, by Jeffrey Lee Flood ; and The Navy Overhaul Policy--A Costly Means of Insuring Readiness For Support Ships, Report by the Comptroller General (GAO). Chapter IV will present a mathematical formulation of the general Navy maintenance optimization problem and discuss some of the reasons why the Navy presently cannot analytically find an optimal way to maintain its ships. A brief discussion of some of the approaches that have been taken to solve scaled-down versions of this problem will also be included. Chapter V will describe the conventional, MSC, and AFS Phased Maintenance Program maintenance policies. A direct comparison of the latter two policies will also be presented. Chapter VI will develop an evaluation of the AFS Phased Maintenance Program (AFSPMP). This will include an analysis of the costs of the four alternative policies, an analysis of the benefits of the AFSPMP, and a determination of the degree to which the AFSPMP has met the objectives that were established for it at the outset of the program. Chapter VII will investigate the question of whether the AFSPMP is a cost-effective alternative to conventional maintenance. It also will address the expansion of the phased maintenance program to other classes of auxilaries, amphibious ships, and large combatants. Finally, Chapter VIII will summarize this thesis and present the resulting conclusions and recommendations.

II. EVOLUTION OF THE CONVENTIONAL MAINTENANCE PHILOSOPHY

Decisions concerning the scheduling and execution of depot level maintenance should be based on maintenance strategies or philosophies. The effect of a particular strategy on total costs, material condition, and ship availability is at the center of the problem. How can the Navy evaluate a potential strategy without actually implementing it and recording the results? Although improvements have been made, the Navy presently does not have any good methods for accurately evaluating alternative overhaul strategies. This either results in the Navy doing nothing or it forces it to experiment at the ship level.

Historically, the Navy has been more concerned with the improvement of ship material condition and overall readiness as a result of a particular strategy rather than the manday or dollar costs of sustaining that strategy. The Navy undoubtedly has caused some overhaul cost growth as a result of its maintenance philosophies.

During the early 1960's regular overhauls were generally very short in duration, typically four months for a destroyer, and involved only one-third or one-fourth the number of mandays expended today [Ref. 5: p. 8]. A direct comparison of past with present is, however, questionable because of the differences in ship complexity, quality and number in ship's crew, and so forth. When the CNO concluded, in the mid 1960's, that the material condition of the fleet was so poor, that it was not adequate for national defense, efforts were made to remedy the situation [Ref. 5: p. 2].

The desire of senior military personnel to improve the material condition of the fleet resulted in many changes to the way in which maintenance, from the organizational level to the depot level, is conducted today. The offshoots of these efforts include, but are not limited to: an increase in the power and importance of the Board of Inspection and Survey (INSURV Board), which periodically inspects each ship and documents all deficiencies in material condition; establishment of a Propulsion Examination Board (PEB) to aid in insuring that 1200 psi propulsion plants were safe to operate; establishment of the Combat Systems Readiness Review (CSRR) which is a weapon and communication systems analog to the PEB; improvements in the Casualty Reporting (CASREP) system (Ships must submit CASREPs whenever a material deficiency or equipment failure occurs that degrades one or more of the ship's mission areas and requires outside assistance or more than ninety-six hours to correct.); enhancement of the Maintenance Material Management System (3M); formalization of Personnel Qualification Standards (PQS) which specify the training required for specific watchstations and provide a very formal framework for the documentation of individual training accomplishments; and establishment of the Ship's Force Overhaul Management System (SFOMS) which provides a structure for scheduling and tracking ship's force work during overhaul. [Ref. 5: p. 2]

Another major result of all of this was the basic maintenance philosophy that prevails within the Navy today. This philosophy is based on the "thorough" overhaul concept which is defined as follows:

> "Upon completion of overhaul, a ship shall be ready for unrestricted war service. All regular overhauls shall be planned to accomplish all outstanding repairs and major maintenance to ensure reasonably reliable material readiness and operations during the succeeding operational cycle." [Ref. 5: p. 3]

For some time the overhaul programming and budgeting personnel have not been able to provide enough funds to complete all of the work requested for Navy ship overhauls. Cost growth due to ship age and fleet modernization does not account for all of the increase in the cost to overhaul ships. One fundamental problem is that under the thorough overhaul policy the people who plan the overhauls and produce the Ship Alteration and Repair Packages (SARPs), part of the initial documentation of what will be accomplished during a specific overhaul, are guided more by risk avoidance than they are constrained by fiscal matters. The end result of risk avoidance is

> "the inclusion of numerous 'insurance items' in the overhaul package, items of repair work for

> which there is no current indication of impending failure, but which are believed needed to ensure the ships's ability to maintain reliable operations throughout its operating cycle." [Ref. 5: p. 31]

The emphasis placed on this strategy resulted in the more formal way in which the Navy currently plans for an overhaul. It also required more lead-time for the planning process due to the scope of work that is accomplished during overhauls. Typically the work to be accomplished is identified a year or more in advance of the scheduled overhaul start date. Unfortunately, this can lead to inclusion of everything that is known to require overhaul attention as well as many items that are not.

There is some question as to whether or not further increases in the mandays or dollars expended on an overhaul, beyond present levels, will result in additional improvements in material condition. In fact, some analysts argue that the Navy is already past the point of diminishing returns and that maintenance budgets should be reduced substantially. There is considerable evidence which indicates the thorough overhaul concept is not an optimal way to conduct the depot level maintenance of Navy ships. Some of the studies addressing that issue are briefly described in the next chapter. As a consequence of these studies and the ever rising costs of ship overhauls, today there is increasing enthusiasm for adoption of so-called progressive maintenance strategies. These strategies are based on depot maintenance availabilities that are shorter in duration and occur more frequently. It is thought that this kind of system will result in less conservative planning for depot level maintenance, therefore reducing the number of unwarranted risk avoidance work requests.

III. INDICATIONS THAT THE CONVENTIONAL MAINTENANCE POLICY IS NOT OPTIMAL

The only pertinent studies that address the AFS Phased Maintenance Program are the program evaluation reports that are produced by the Amphibious and Combat Support Ship Logistic Division of the Surface Ships Directorate of the Naval Sea Systems Command (NAVSEA 911), in conjunction with American Management Systems, Inc. Three formal reports have been published to date. The most recent one was published in August 1983 and is titled AFS Phased Maintenance Program, Third Formal Evaluation Report. These reports are not summarized or discussed in this chapter because portions of them will be used as sources of data and information in Chapters V through VII.

Several studies, however, have addressed the fact that during the early 1970's the Navy's cost of maintaining a fleet oiler (AO) were far greater than the corresponding costs for MSC tankers/fleet oilers, and enormously greater than the costs for commercial ships [Ref. 2: p. 10]. This result was particularly important in studies that have focused on the question of civilianization of some classes of auxiliary ships. The Government Accounting Office (GAO) and the Congress have also used results from these studies to help document their claims that the Navy is wasting resources by using its present overhaul philosophy. Several of these studies will now be examined in detail.

A. SOAMS PROJECT: A STUDY OF SHIP OVERHAUL AND MAINTENANCE

The Ship Overhaul and Maintenance Study (SOAMS) was conducted by Cooper and Company from January 1973 to November 1975. The study was designed to find ways to reduce Navy maintenance costs, without reducing the performance of ships, and was done in four major steps: (1) Phase I: Demonstration Approach; (2) Phase II: Reducing Costs of Navy AO Overhauls; (3) Effects of Implementation; and (4) Plans for Test and Evaluation. The first two steps are of particular interest so the basic methodology and results are briefly discussed in the following paragraphs.

1. Phase I: Demonstration Approach

The objective of this phase was to demonstrate an approach to finding improvements in fleet maintenance. The basic approach was to study the costs and ship performance for several organizations with broadly different maintenance policies. Cooper and Company chose to do this by analyzing data for USN fleet oilers (AOs), MSC tankers, and commercial tankers from a U.S. oil company. Some of the differences among the three sets of ships were identified and appropriate adjustments to the data made. Table I summarizes their findings with respect to overhaul costs and ship performance. Based on their numerical results

Cooper and Company stated,

> "The costs of maintaining an AO, at any level of design detail, are far greater than the corresponding costs of an MSC tanker, and enormously greater than the costs of maintaining a commercial tanker; and this is true whether we consider overhaul costs alone, or interoverhaul costs alone, or the sum of the two. At the same time AOs have more CASREPs, as well as lower availability." [Ref. 2: pp. 2-4]

It was also reported that the average time between overhauls was 42 months for USN ships, 18.5 months for MSC ships, and 22 months for commercial ships. The results were based on a study of 14 AOs, 19 MSC tankers, and 9 commercial tankers [Ref. 2: pp. 3-6].

TABLE I

SOAMS Project--Phase I Findings
Ratio Comparisons of Cost and Performance

MEASURES OF COST AND PERFORMANCE	RATIO OF AOs TO MSC TANKERS	RATIO OF AOs TO COMM. TANKERS
ANNUAL COSTS:		
(1) OVERHAUL		
REPAIRS	3.1	10.5
ALT.'S	4.2	2.5
(2) BETWEEN OVERHAULS		
RAV,TAV,ETC.	5.7	9.0
ON BOARD CREW	4.5*	4.5*
ON BOARD MAT.'S	N/A	1.9
PERFORMANCE:		
(1) SHIP DOWNTIME		
DUE TO OVERHAUL	1.8	3.0
DUE TO OTHER REPAIRS	3.8	6.1
(2) SHIP AVAILABILITY	.91	.80
(3) CASREPS (3/4)**	1.35	N/A

* Minimum crew ratios vary between 3 and 6, depending on class of ship.

** CASREPs rated 3 and 4 generally seriously degrade one or more mission areas.

[Ref. 2: p. 3]

2. Phase II: Reducing Costs of Navy AO Overhauls

The difference in overhaul costs revealed in Phase I were hypothesized to be due to one or more of three factors: (1) differences in the physical conditions of the ships at the beginning of an overhaul, including differences due to operating tempo, design, or interoverhaul maintenance; (2) differences in overhaul planning, that is, the processes that determine what work will be performed once the ship goes into overhaul; and (3) differences in the shipyards conducting the actual overhauls. Cooper and Company felt it was necessary to establish the source of the differences in overhaul costs before they made any specific recommendations for ways to reduce costs. The basic approach was to identify MSC and USN ships that were in very nearly identical physical condition and compare the overhaul costs for that set of ships. This included having MSC prepare overhaul estimates on the Navy military manned ships. The major finding for Phase II was that in situations where the physical conditions were identical, the Navy overhaul costs were two times those of MSC and five times those of the oil company [Ref. 2: p. 10]. They concluded that

> "The comparisons make it virtually certain that the overhaul cost differences observed in Phase I between the three jurisdictions must be due to (1) overhaul planning and implementation differences and (2) differences in physical conditions. It is also clear that both effects are substantial." [Ref. 2: p. 14]

B. A COMPARISON OF MANNING OPTIONS FOR THE AO-177 CLASS FLEET OILER

This study was performed by Lieutenant Commander J.L. Flood while a student at the Naval Postgraduate School. It was submitted in October 1982, in partial fulfillment of the requirements for a degree of Master Of Science in Management. The study developed comparative life cycle costs for the Navy military and Navy military-conversion to civil service manning options for the AO-177 class fleet oiler. The comparison revealed that the primary difference between the total annual costs for the two manning options was due to maintenance. The total annualized depot and intermediate level maintenance cost under military manning was estimated to be more than two times that of the civil service manning option [Ref. 6: pp. 32-35].

C. THE NAVY OVERHAUL POLICY--A COSTLY MEANS OF INSURING READINESS FOR SUPPORT SHIPS

This analysis was conducted by the General Accounting Office (GAO) at the request of the House Committee on Appropriations. The request was made 19 October 1977 and the results were published 27 December 1978. The committee requested that GAO: (1) compare maintenance practices for U.S. Navy auxiliary and amphibious ships, with civilian American flag commercial ships, and (2) obtain and compare statistical data on overhaul costs and maintenance practices for U.S. Navy ships overhauled in private yards with those for similar commercial ships. The GAO study was primarily an analysis of differential expenditures and did not fully address the cost-effectiveness of the various maintenance policies examined.

The GAO reported that the Navy's maintenance costs per ship average about two million dollars as opposed to about four-hundred thousand for a similar commercial ship. Much of the report was devoted to discussing some of the reasons for such a great difference. They briefly described the differences in the missions of the ships and the fact that, since Navy ships are designed to operate in combat environments, they are equipped with many battle systems and armaments, large crews, and extensive backup systems. GAO concluded that

> "though we had problems in obtaining valid data, the cost differences are so marked that no refinement of data or approach can significantly alter the broad finding--that the Navy spends more maintaining its ships, including specific equipment." [Ref. 7: p. 1]

The GAO also addressed the issue of what equipment reliability is needed for support ships. They stated that the Navy does not adequately assess the likelihood of equipment failure and that

> "... without these detailed assessments, the Navy has adopted a philosophy of high-cost overhauls to better insure reliability during operating cycles. As a result, equipment that is operating satisfactorily or with only minor problems may be overhauled." [Ref. 7: pp. 11-12]

This led to a discussion of reliability centered maintenance, which has been used with success by civilian aircraft companies. The basic premise of this maintenance philosophy is that scheduled maintenance is not always effective, desirable, or economical. The basic principle is to perform only those maintenance tasks that are necessary to retain design levels of safety and reliability. This concept requires that each maintenance task that has been determined to be required or desirable is classified as either "fixed frequency" or "on-condition maintenance." The remaining maintenance items are designated for "condition monitoring." Fixed frequency maintenance applies to those equipments or components which demonstrate a predictable relationship between age and reliability degradation. The items are generally removed and then replaced or overhauled at some maximum time interval. On-condition maintenance applies to items for which periodic inspections or tests can determine their condition. Maintenance is then scheduled as dictated by the inspections or tests. Condition monitoring refers to those equipments or components that are not subject to an effective maintenance action. The failure history of this type of equipment is monitored and evaluated for possible reclassification or redesign. [Ref. 7: p. 15]

Reliability centered maintenance is especially effective when one considers that many types of equipment fail with an exponential probability distribution. Items that fail exponentially exhibit a very interesting memoryless property. This means that the conditional probability distribution of the failure of an item at some time t is the same as the unconditional probability distribution of the item at time zero, or at any other time. For example, assume that lightbulbs fail exponentially. Then, the probability that a lightbulb fails during the next fifty hours of operation, given that it is brand new, is the same as the probability that it fails during the next fifty hours, given that the bulb has been burning for five-hundred hours. In addition, if the mean corresponding to the probability distribution is 1000 hours, then at any point in time the expected life remaining in the lightbulb is 1000 hours. This implies that overhauling or replacing an equipment or component will not provide any additional reliability. The results of ongoing research in the airline community provide an example of this. Figure 1 shows the age-reliability relationships from a United Airlines study.[1] It indicates that ninety-four percent of the components examined do not require periodic overhauls.

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[1]Statement of Mr. Tom Matteson, Consultant, Maintenance and Systems Failures, Airline Community, before the Senate Appropriations Subcommittee on Defense, on 14 September 1983.

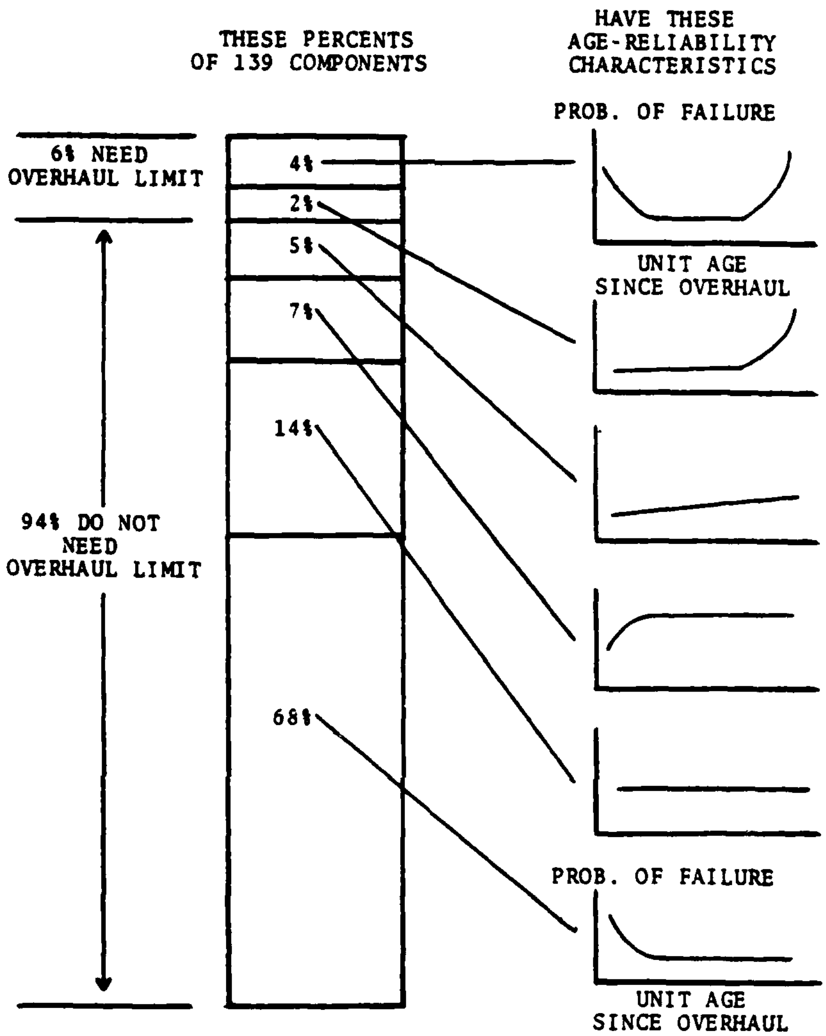

Figure 1 Age-Reliability Relationships from a United Airlines Study

D. CONCLUSIONS REGARDING NAVY OVERHAUL COSTS

The three studies briefly described above, as well as many others, strongly indicate that the Navy spends more money overhauling its ships than do MSC and commercial operators. However, there may be good reasons for the higher costs, so the real question is whether those higher costs are justified. The differences in the design of the ships, missions, crew size and experience, and type of operations must all be weighed very carefully. Despite the fact that the basic mission of MSC fleet oilers is the same as Navy military manned fleet oilers (AOs), the ships are operated in very different ways. In comparing Navy ships to commercial tankers, great care must be taken to control for differences in ships, missions, and operations. An often stated criticism of the Navy is that it spends more than MSC or commercial shipowners to maintain its ships yet keeps them at sea for a smaller percentage of the year. Those statements, however, do not consider the fact that the amount of time a ship is underway has a direct influence, both positive and negative, on the maintenance costs. Many naval officers have observed that ships "run best" when they do a lot of steaming. The point is that the differences between the ships being compared may partially or totally invalidate the comparisons that have been made.

Since there is a strong indication that the Navy may be able to find a better maintenance policy than the one it is currently using, why cannot the Navy simply input the applicable variables into a computer, generate a solution to the problem, and print out the optimal policy that it should follow? This question will be answered in the next chapter.

IV. THE NAVY SHIP OVERHAUL OPTIMIZATION PROBLEM

The Navy ship overhaul problem is an extremely complicated optimization problem that has not yet been fully solved. The objective of the problem is to find an optimal strategy for maintaining ships in a high state of readiness without incurring unreasonable costs. In the broadest sense, the Navy is interested in optimally determining how much work to accomplish during each overhaul, the duration of each overhaul, the overhaul frequency, and the amount of interoverhaul depot level maintenance to perform. It should be noted that these decisions are not independent of each other. Overhauls scheduled for long periods of time are much less likely than short ones to be completed on time and on budget. Reducing the scope of overhauls and hence the cost may conceivably result in increased failure rates and, subsequently, an increase in the frequency of emergency repairs. In addition to the high cost of emergency repairs a ship may not be available for an operation, which may itself impose additional costs. There are also direct ramifications of these decisions with regard to Navy force levels. The overhaul duration and the time between overhauls roughly establish an upper limit on the overall availability of a ship. This directly influences the number of ships the Navy must have in commission to satisfy specific requirements to meet national security objectives. A very important indirect result of all of this is the material condition of a ship now and in the future. Without proper planning and careful attention to detail it is possible to inadequately maintain a ship but not find out about it for several years. Wars typically require that ships be deployed for extended periods of time resulting in postponed and/or cancelled overhauls. Although the ships involved are generally able to meet their wartime commitments it is not unusual for their material condition to slowly deteriorate, resulting in less capable ships after some period of time.

A. MATHEMATICAL FORMULATION

The primary purpose of this formulation is to give the reader a feeling for the complexity of the ship overhaul problem. It will also be a useful tool later in this study for discussing the cost-effectiveness of one maintenance policy compared to another. The formulation here is considerably less complex than would be required in the real world but it does provide a good starting point.

The objective of the formal optimization problem is to allocate depot and intermediate level maintenance budgets and determine the duration and frequency of overhauls for a small group of similar ships (the Atlantic Fleet AFSs, for example), given a series of relatively inflexible constraints. The basic formulation could easily be revised so that one ship only is considered or generalized to include entire classes or fleets of ships. The following variables are defined for the purposes of the formulation:

- MOE - measure of effectiveness for the group of ships,
- N - number of ships in the group,
- OD - duration of an overhaul,
- OF - overhaul frequency,
- BT - total dollar budget available for intermediate and depot level work for the N ships,
- Bi - dollars budgeted for ship i,
- DT - total depot level mandays available for the N ships,
- DOi - depot level mandays of work scheduled for ship i during an overhaul,
- DBi - depot level mandays of work scheduled for ship i between overhauls,
- IT - total Intermediate Maintenance Activity (IMA) mandays available for the N ships,
- Ii - IMA mandays of work scheduled for ship i between overhauls,
- CMO - mandays of organizational level maintenance performed by ship's crew during overhaul,
- CMB - mandays of organizational level maintenance performed by ship's crew between overhauls,
- AV - percentage of total time ship is available for fleet operations,
- CA - casualty reports (CASREPs) per unit time,
- TR - training status,
- SCH - required schools and off-ship training,
- R - reliability (probability ship completes fleet operations without mission degrading casualties, given all systems are up at the start of operations),
- FMP - accomplishment of fleet modernization SHIPALTs (ship alterations),
- LV - leave and liberty, and
- AGE - ship age.

The units of measurement are not specified for some of the variables because it is not clear what that measure would be in the real world. As indicated in the definitions above, subscript i refers to ship i. An additional subscript for referring to individual ships is required for clarity. In the formulation below subscript j refers to the amount of a particular attribute possessed by ship j and subscript o refers to a specified minimum or maximum level of that attribute. Then the optimization problem may be formally stated as:

$$
\begin{array}{lll}
\text{MAXIMIZE} & : & MOE = f(OD, OF, BT, Bi, DT, DOi, DBi, IT, Ii, CMOj, \\
& & \quad CMOo, CMBj, CMBo, AVj, AVo, CAj, CAo, \\
& & \quad TRj, TRo, SCHj, SCHo, Rj, Ro, FMPj, FMPo, \\
& & \quad LVj, LVo, AGEj, AGEo) \quad i,j = 1,\ldots,N \\
\text{SUBJECT TO} & : & \text{(1) TOTAL DOLLAR BUDGET} \\
& & \quad \sum Bi <= BT \\
& & \text{(2) DEPOT/IMA FACILITIES} \\
& & \quad \sum DOi + \text{sum } DBi <= DT \\
& & \quad \sum Ii <= IT \\
& & \text{(3) ORGANIZATIONAL MAINTENANCE} \\
& & \quad CMOj <= CMOo \\
& & \quad CMBj <= CMBo \\
& & \text{(4) SCHEDULED COMMITMENTS} \\
& & \quad AVj >= AVo \\
& & \text{(5) READINESS} \\
& & \quad CAj <= CAo \\
& & \quad TRj >= TRo \\
& & \quad SCHj >= SCHo \\
& & \text{(6) RELIABILITY} \\
& & \quad Rj >= Ro \\
& & \text{(7) FLEET MODERNIZATION PROGRAM} \\
& & \quad FMPj >= FMPo \\
& & \text{(8) PERSONNEL} \\
& & \quad LVj >= LVo
\end{array}
$$

The mathematical formulation above basically states that the Navy should maximize the "effectiveness" of its ships subject to the following constraints: (1) the total dollars expended on the ships must not exceed the allocated budget; (2) the total depot and total intermediate level mandays expended to maintain the ships must not exceed the mandays available; (3) the amount of maintenance that can be performed by the ship's crew is physically limited by the number in the crew, watchstanding duties, training, leave and liberty, etcetera. Ship's crew may or may not be able to accomplish jobs that are not completed at the depot or intermediate levels; (4) each ship must be available to meet scheduled commitments; (5) when available for fleet operations each ship must be capable of performing its assigned missions--the equipment must be operational and the ship's crew must be trained to use it (team training aboard ship and schools ashore); (6) the probability that a ship can complete fleet operations, without suffering mission degrading equipment casualities, must be sufficiently high; (7) designated fleet modernization SHIPALTs for habitability and weapon system updates must be completed; and (8) the ship's crew must be given a reasonable opportunity for leave and liberty while inport. Extended deprivation of leave and liberty can lead to poor morale, serious readiness problems aboard a particular ship, and lower retention of personnel in the Navy. Low retention may affect the quantity and quality of shipboard personnel, resulting in ships that are degraded in their ability to perform their mission.

The objective function of the optimization problem was defined as a very nonspecific MOE that is a function of many variables. This was the simplest way to indicate the complexity of the objective function without making assumptions about the actual format and functional relationships. The values for the constraints would be fixed at the appropriate level of decision making. Some of the constraints are the result of physical limitations while others could be interpreted as goals that the Navy is striving to achieve. The constraints are not exhaustive and serve only to indicate the variety of factors that constrain the optimization problem. Several confounding aspects of the optimization problem are addressed in the following section.

B. SOLUTION DIFFICULTIES

The mathematical formulation above is not specific regarding the objective function and the constraint equations. One cannot mathematically determine the optimal solution to the problem and promulgate a new maintenance policy because of the inability to specify intervariable relationships and establish a valid set of functional forms for the MOE and constraint equations. Optimality considerations will be discussed in more detail later in this chapter.

1. Measures of Effectiveness

One major problem that is repeatedly encountered in attempting to solve this and related problems is defining an adequate measure of effectiveness (MOE). An MOE is a quantitative assessment of the degree to which the objective of an analysis is satisfied. It is used to compare the effectiveness of alternative courses of action in achieving the stated objective. The MOE is extremely critical in terms of producing meaningful results from any attempt to solve the problem.

Raisbeck [Ref. 8: pp. 85-86] details a way of determining a measure of effectiveness that is particularly appropriate for the optimization problem above. The basic methodology is to analyze the parallels between mathematical or other representations and the real world. If the analyst has a sufficient understanding of the problem this may result in the establishment of valid functional relationships.

It is generally straightforward to make proportionality or sign statements about each of the variables included in the objective function stated in the problem formulation. However, actual determination of a set of valid functional forms and their associated weights is extremely difficult. This is due to the fact that Navy analysts presently do not understand the intricacies of all of the interactions among the variables included in the objective function. In addition, there are many different views on how to measure ship effectiveness.

In the past, many different MOEs have been proposed. Kline [Ref. 9: p. 8] quoted Welker and Horne's early 1960's statement that "System Effectiveness is the probability the system can meet an operational demand within a given time when operated under specific conditions." Kline [Ref. 9: p. 8] also reported that Von Alven expressed this definition of system effectiveness as the product of three probabilities: (1) the probability that the system is either operating satisfactorily or can be placed in demand at any random point in time; (2) the conditional probability that the system will operate for the duration of the mission, given that it was operable at the start of the mission; and (3) the probability that the system can meet mission requirements, given that it is operating within its design specifications. This seems to be a very applicable MOE and may take into consideration all of the influencing factors that were defined in the formulation. It would, however, be extremely difficult to make the required numerical determination of the probabilities.

Most of the recent studies use the availability of the ship or the total maintenance cost as the MOE but this author believes this forces too simplistic a problem and results in less than adequate (and useful) results. It should be noted that, in fact, very few studies have attempted to address more than one or two aspects of this problem at a time. There are many more factors of interest and importance that cannot be validly detached from the problem.

2. Confounding Aspects

In addition to the MOE problems that must be resolved there are several additional, yet unspecified, confounding aspects of the overhaul problem. Six of these are briefly addressed in this chapter. Although the six items mentioned below are not exhaustive, they do give some feeling for the kinds of things that influence overhaul policy decisions. Some of these are basically constraints to the optimization problem if the ship has not yet been designed and constructed.

a. System Reliability

The design of every ship is based in part on system reliability specifications. Clearly, a relationship exists between the reliability of a system (an entire ship) and the cost to maintain it.

b. System Maintainability

Maintenance requirements, for depot or intermediate level work, certainly depend on the way in which the various equipments were designed to be maintained.

c. Ship Age

There is some indication that as a ship ages it costs more to keep it performing to the required specifications. In addition, maintenance costs in any particular year are generally not independent of the maintenance policies that may have been in effect during previous years. Likewise, the prior utilization or employment of a ship may have a significant impact on current maintenance costs.

Another interesting and potentially confounding aspect regarding ship age is the intended service life of a ship. This can obscure the underlying differences among various alternative maintenance policies. It also confounds the selected MOE because Navy ships are routinely operated past the typical thirty year life for which they were designed. It is not unreasonable to expect that ships operated well past their expected life may cost more to maintain and may be somewhat less capable than when they were new.

d. Standards and Regulations

Safety, engineering, and general maintenance standards and regulations periodically change throughout the operational life of a ship. A good example of this is the creation and operation of the Propulsion Examination Board (PEB).

e. Fleet Modernization Program

Ships periodically are updated or augmented with new weapon systems and often improvements in habitability are made. Some alterations consist of replacing outdated or inoperable equipments with new ones;

therefore, the need for repair work may be reduced. Ship alterations (SHIPALTs) also may have a substantial impact on the future requirements for maintenance and repair.

f. Politics

Another problem that makes the Navy's overhaul problem more difficult to solve is the influence of non-Navy constituencies. These constituencies impact upon the Navy in areas such as the environment, social welfare, and labor and business. In studying the evolution of surface ship overhauls American Management Systems, Inc. concluded that

> "... the Congress, in its role as representative of special interest groups and as a source of budgetary decision-making, is increasingly involved in the management of the ship overhaul process. In part, this is in support of social programs such as ensuring that small businesses receive a substantial share of ship overhaul work. Part has been dictated by the perceived decline of the U.S. shipyard industry. In many cases, regional economic considerations influence work allocation. Whatever the social consequences of involvement by the Congress, the results for the Navy are reduction of its flexibility to manage the ship overhaul program in its own best interest, and probably creation of some major cost disadvantages as well." [Ref. 5: p. 41]

It is reasonable to conclude that the political pressures associated with military fiscal matters result in an additional set of potentially confounding variables.

3. Data Dependence

Another major difficulty is that most approaches to solving the optimization problem require an extensive data base. The data base must incorporate many observations and preferably they should represent a variety of overhaul and interoverhaul durations. In addition, as a model is made more complex and, hopefully, more meaningful, the dependence on data generally becomes greater.

Although extensive ship maintenance data is available, in reality these data are the result of relatively few maintenance policies. This results in the so-called "out of range" problem. Many statistical methods require data for estimates of equation coefficients, transition probabilities, and functional relationships. When evaluating alternative maintenance policies that are not represented in the data base, the validity and reliability of these estimates are questionable due to the out of range problem.

C. SOLUTION APPROACHES

Many attempts have been made to analytically address the optimization problem. By necessity, however, all have been attempts to solve somewhat restricted versions of the problem. Although it would be nice to be able to directly generate an optimal maintenance policy, solving the scaled-down problems is beneficial in two ways. First of all, until one can solve the "easier" problems it does not make much sense to expend a lot of energy trying to solve the harder ones. Therefore, these smaller problems can be likened to stepping stones. Secondly, the results of the scaled-down versions of the problem are interesting in their own right and do provide some useful information.

There are many ways to approach the scaled-down versions of the optimization problem. Four basic approaches that have received much attention are presented below.

1. Regression Analysis

Without a doubt, the primary thrust of research in this area using regression techniques has been in developing cost estimating relationships (CERs). Statistically sound CERs that relate overhaul dollar and manday costs to overhaul duration, overhaul frequency, and other variables clearly have the potential to aid in solving the larger optimization problem by helping to specify intervariable relationships.

The Center for Naval Analyses has conducted a significant amount of research in this area. Their report on ship overhaul cost estimating relationships (SOCERs) received much attention and revealed many interesting things about the general problem. For example, they state, "Analysis of overhaul data covering fiscal years 1962-1972 indicates that increased overhaul costs were not associated with longer (interoverhaul) intervals, with the exception of aircraft carriers." [Ref. 10: p. iii] This was not an intuitively obvious result. Since their research was conducted on combatants and is now eight years old one may question the validity of their conclusions with respect to the situation under analysis here. In addition, even if less frequent overhauls are not associated with increased overhaul costs, they may be associated with increases in other maintenance costs.

The most significant problem with approaches using regression analysis is the dependence on historical data. The reliability of an estimate from a regression equation may be questionable when the values for the inputed variables are beyond the sample range. This may be due to one or both of two factors: (1) it is quite possible that the regression equation does not hold beyond the range of the data; and (2) values beyond the range of the data may be from a different population than the original data [Ref. 11: p. 46]. Another significant limitation is that although the CERs might do very well in describing how the independent and dependent variables were related in the past, there may be unrepresented and potentially confounding variables that could invalidate the regression model.

One particularly appealing method that could be applied to this problem was presented in a course on test and evaluation at the Naval Postgraduate School by Professor G.F. Lindsay. The basic method involves merging expert opinion with regression techniques. This method could be extremely useful in determining how ship maintenance and readiness experts feel about the assorted variables in the objective function of the optimization problem. The goal would be to explicitly define the mathematical form of the MOE. For this situation a survey (questionnaire) would be prepared and distributed to experts. The survey would contain a presentation of the numerical values for each of the variables included in the objective function for as many maintenance policies and ships as possible. The judges would be asked to do numerical ratings, rankings, categorical judgements, or the constant sum method. The resulting scaled values for the MOE, which would be on an interval or ratio scale, would then be used as the dependent variable (as cost was in the SOCER study) for a regression analysis. The resulting regression equation could be used to determine the value of the MOE under a variety of alternative maintenance policies. This method is appealing because it incorporates both expert opinion and accepted statistical analysis.

2. Markov Process

Another interesting way to approach the problem is through stochastic models. Within the general framework of stochastics, the most appropriate method seems to be Markov processes. A scaled-down version of the Navy overhaul problem has been successfully modeled using transient Markov processes. Eldred [Ref. 12] developed a set of increasingly general models that resulted in a reasonable way to evaluate maintenance policies. The final and most complex model was able to accomodate inputs for ship age, material condition, and elapsed time out of overhaul. The development of these models was very complex and beyond the scope of this chapter. The description of the model is therefore brief and in general terms.

In the most complex model, Eldred established four levels of material condition, three categories for time since overhaul, and three categories for ship age. He then estimated transition probabilites using historical data from destroyer type ships.

The model was somewhat flexible in that it was able to evaluate a wide range of maintenance policies. The results of the study indicate that the Markov process was a reasonable way to describe the changing material condition of ships over time and how the overhauls affected it. Although this model has much potential for evaluating alternative maintenance policies it suffers from the same limitations as most other models. The first limitation is that one must be able to either subjectively or quantitatively categorize a ship's material condition. The second is that the model is not valid unless the transition probabilities are accurate and reliable. Transition probabilities must be computed using historical data or assumed through some kind of subjective evaluation. The use of historical data may result in out of range problems similar to those that can be encountered in regression analysis.

3. Dynamic Programming

Dynamic programming is a very good solution strategy for the problem at hand. Using this approach, recursive equations are derived that allow one to solve the problem one step at a time. Jardine [Ref. 13: pp. 118-125] developed a basic dynamic program that he called: "optimal overhaul/repair/replace maintenance policy for equipment subject to breakdown : finite time horizon." The basic model accomodates either a good or failed state of equipment, a series of possible maintenance actions that can be taken during a period, and transition probabilities for describing the probability that the equipment will go from state i to state j in one period if maintenance action "a" is taken. It also incorporates the cost of transition from one state to another. The objective of the program was to minimize the total cost of maintenance over n time periods.

The model can easily be generalized to accomodate the overhaul problem. The number of discrete material condition states can be expanded to any reasonable number and stochastic extensions (for increasing probabilities of failure, etcetera) can easily be incorporated in the model. The model is not, however, without limitations. It also is very dependent on accurate and complete historical data for determination of the transition probabilities. The model also requires some method for discretizing the material condition of a ship, based on the available data.

4. Trial and Error

The best way to utilize the trial and error approach is to conduct a completely valid scientific experiment. Ideally, some of the ships would be identified as test ships and others as control ships. All factors would then be held constant with the exception of the maintenance policy. In addition, a large number of control and test ships would be used to reduce the variance of the statistics used to describe the results of the experiment. This cannot realistically be accomplished by the Navy due to the sheer magnitude and scope of the problem. It is useful, however, for the Navy to adhere to as many of the basic principles as possible.

Professor G.F. Lindsay defines an experiment as a series of controlled observations taken in an artificial environment, with deliberate manipulation of some variables, in order to answer one or more specific questions. He also maintains that all experiments are artificial in that: (1) they are created by people; (2) people in experiments behave unnaturally; and (3) the presence of an experimenter imposes an artificial flavor on the test. In planning any experiment or test program the experimenter should consider the populations to which the results are supposed to pertain. In addition, the experimental design should produce an estimate of the property being tested and the experimental error.

As previously stated, the Navy's primary method for evaluating potential maintenance strategies has been through actual implementation (experimentation). A very good example of this is the AFS Phased Maintenance Program (AFSPMP). Unfortunately, these test programs are not generally conducted as scientific experiments. For example, the AFSPMP uses the same three Atlantic Fleet AFSs as both the test and control ships. The current five year operating cycle is considered for the test ships and the previous five year operating cycle for the control ships. It is doubtful that all factors other than the maintenance policy have been held constant. The use of a nonscientific experiment may lead to possible questions concerning the validity and applicability of the results.

D. OPTIMALITY CONSIDERATIONS

One should recall that in the broadest sense, the Navy is interested in optimally determining how much work to accomplish during each overhaul, the duration of each overhaul, the overhaul frequency, and the amount of interoverhaul depot level maintenance to perform. These are the basic decision variables for the optimization problem.

In order to discuss the optimality of a maintenance policy two definitions are required. In terms of the formal optimization problem a solution is feasible if and only if the eight sets of constraints are satisfied. A trial optimal solution X^* is a global maximum for the optimization if and only if for all feasible X:

$$MOE(X^*) >= MOE(X).$$

Unfortunately, in real world problems such as the Navy overhaul problem it is often the case that one or more of the constraints are violated. The FY 75-79 conventional policy is a good example of this. One may recall that a primary objective of the AFSPMP was to minimize the duration of depot level maintenance periods to facilitate keeping one of the AFSs forward deployed at all times. This was driven by an unequal sharing of deployments prior to the implementation of phased maintenance. Precise availability figures are not required to speculate that the conventional policy probably violated constraint four, the scheduled commitment constraint, and possibly five and six, the readiness and reliability constraints, as well.

The determination or assessment that a particular policy is optimal also requires the functional form of the objective function and constraints to be known. Since the Navy has not been able to do this, the optimality of the AFSPMP cannot be established in this study.

E. CONCLUSION

The only reasonable conclusion that can be reached after an intensive review of the literature is that the Navy presently does not have the ability to completely solve its overhaul optimization problem. This does not mean that the Navy should be held culpable for its inability to solve the problem. Indeed, the complexity of the optimization problem is such that it may never be solved. A major difficulty is that the Navy does not have enough data or knowledge to establish the relationships in the constraints and MOEs.

Due to the Navy's inability to reliably predict the consequences of alternative maintenance policies, the Navy is left with only one course of action: implement a maintenance policy and analyze the results to see if it is any better than the previous one. This is what the AFS Phased Maintenance Program (AFSPMP) test bed attempts to do: implement a maintenance policy similar to the one employed by the Military Sealift Command (MSC) and see if it meets the established goals. The following chapter will describe the conventional, MSC, and AFSPMP maintenance policies. A direct comparison of the latter two policies will also be presented.

V. OVERVIEW OF CONVENTIONAL, MSC, AND AFSPMP MAINTENANCE POLICIES

Chapter II described the evolution of the thorough overhaul concept, which forms the basis for the conventional maintenance policy that is applied to most of the surface fleet. Chapter III reviewed several pertinent studies that strongly indicate the Navy may be able to find a better maintenance policy for its support ships. The conclusion reached in Chapter IV was that the Navy currently has only one method for reliably evaluating alternative maintenance policies--implement a trial optimal policy and analyze the results. Such a trial maintenance policy was authorized by the Navy in 1979 for Atlantic Fleet AFSs and is called the AFS Phased Maintenance Program (AFSPMP).

The remainder of this chapter will briefly describe the conventional, Military Sealift Command (MSC), and AFSPMP maintenance policies. A direct comparison of the MSC and AFSPMP policies will also be presented since the AFSPMP was modeled after MSC maintenance practices. The purpose of this chapter is to give the reader additional background information to aid in understanding and interpreting the AFSPMP program evaluation presented in the next chapter.

A. CONVENTIONAL

The conventional maintenance policy is based on the thorough overhaul concept that was discussed in Chapter II. The premise of this policy is that

> "Upon completion of overhaul, a ship shall be ready for unrestricted war service. All regular overhauls shall be planned to accomplish all outstanding repairs and major maintenance to ensure reasonably reliable material readiness and operations during the succeeding operational cycle." [Ref. 5: p. 3]

This policy is therefore predicated on risk avoidance. The major elements of the conventional maintenance policy are described in the paragraphs below.

A conventional maintenance policy is generally characterized by a long overhaul, typically four to twelve months, followed by a long period of operations, usually three to eight years. For some classes of ships periodic Selected Restricted Availabilities (SRAs) are scheduled between overhauls. Unscheduled depot level maintenance, in the form of voyage repairs or Restricted Availabilities (RAVs), may also be required. Intermediate Maintenance Availabilities (IMAVs) are also scheduled periodically and the ship's crew performs organizational preventive and corrective maintenance. The AFSs, under the conventional policy, were scheduled for overhauls of four months duration, and overhaul intervals of fifty-four to sixty months [Ref. 14]. It should be noted, however, that each of the last two regular overhauls completed under the conventional policy were approximately seven months long (see Table B-1 in Appendix B). The AFSs were scheduled for IMAVs but not for SRAs. Organizational level maintenance and unscheduled depot level maintenance were conducted as necessary.

Another important aspect of this maintenance policy is the planning structure. The thorough overhaul concept resulted in the ship and various shore facilities starting to plan for an upcoming overhaul at least one year in advance. It also resulted in attempts to standardize overhauls, through the preauthorization of repair work, to aid in predicting required manday and dollar costs, allow time to order materials that are difficult to obtain, and to make the planning and execution process work more smoothly. The baseline Ship Alteration and Repair Package (SARP), developed by the Planning and Engineering for Repairs and Alterations (PERA) organization, is used as an initial list of repairs. In addition, there are ship-generated work requests for items desired to be included in the overhaul package. The Navy also conducts a very extensive, time-consuming Pre-Overhaul Test and Inspection (POT & I) of the ship and makes recommendations about the work that should be performed. These recommendations are then merged with the baseline SARP and ship's force work requests to form the preliminary SARP. The preliminary SARP provides a foundation for the overhaul package. In the end, three other SARPs are generated as well: proposed, authorized, and completed. The first two result from the various conferences that are convened to revise the SARP as the overhaul approaches. The third documents the work that was actually accomplished during the overhaul.

The bidding and contracting methods employed by the Navy can have a substantial impact on the cost of ship overhauls. For personnel reasons, it is very desirable for a ship to be overhauled in a shipyard that is within close proximity to its homeport. Unfortunately, this may tend to drive overhaul costs higher than they might otherwise be. Bids are not generally restricted to just one location, so some ships are overhauled away from homeport. Under the conventional maintenance policy the Navy historically has used fixed price Master Ship Repair (MSR) contracts for ship overhauls and repairs. The basic purpose of these contracts is to establish the terms of the overhaul in advance. Since conventional overhauls are planned a year or more in advance, the scope of the actual work that will be performed during the overhaul may not be known until after the pricing is accomplished for the contract. In their report on the AFSPMP contract vehicle, American Management Systems, Inc. concluded that the

> "...use of a fixed price MSR frequently leads to optimistic pricing on the part of the competitors in an effort to win the awards, with quality, legal and administrative difficulties developing when the true extent of the work is finally known." [Ref. 15: p. 9]

B. MSC

MSC takes a somewhat different approach to maintaining its ships. The MSC maintenance policy is based on "prudent risk", which implies that the policy is based on the idea of using actual material condition as the primary determinant of repair work. Repair work generally is not authorized if there is no current evidence that it is necessary.

The MSC maintenance policy is characterized by relatively short and frequent overhauls. Some of the maintenance is dictated by Coast Guard and/or American Bureau of Shipping (ABS) standards. MSC overhauls are approximately one or two months in duration and are scheduled every other year. In addition, a mid-period inspection is usually performed between the tenth and fourteenth month out of overhaul. During this two to three week period, voyage repairs and ABS required inspections are completed. Organizational level preventive and corrective maintenance is performed throughout the operating cycle as necessary.

MSC manned ships usually have a crew that is less than one-half the size of its military counterpart. However, an MSC crew tends to have a greater capability to perform preventive and corrective maintenance because it has much more experience than Navy crews. Chief engineers are a good example. MSC chief engineers are better qualified than naval officer chief engineers due to their extensive experience and greater familiarity with their vessels. The end result is that MSC crews can often make repairs for which a Navy crew would require off-ship assistance.

Each MSC ship is assigned a land-based port engineer who is charged with the responsibility of monitoring and planning the repair work. Port engineers are experts in the area of ship repair and are assigned to individual ships on a continuing basis. This allows them to become extremely knowledgeable about the machinery and equipment performance history of the ships assigned to them. The end result is that the port engineer is in an excellent position to provide continuity to the long-run maintenance effort.

Maintenance planning under the MSC policy is much less complicated than it is under the conventional one. Several months before an overhaul is to start the port engineer asks the chief engineer for work requests. The port engineer then reviews the requests and may, at his option, inspect some or all of the items referred to in the requests. The port engineer then decides which of these items will be included in the overhaul and supervises the writing of the overhaul specifications. There are also a variety of standard items that are routinely accomplished during overhaul. Jobs requiring large dollar or manday expenditures may require approval from the area engineering officer, who is responsible for all of the port engineers in his area. The port engineer may also prepare baseline cost estimates and is involved in the contract preparation and bidding process.

The bidding for MSC overhauls is not nearly as geographically restricted as it is for active support ships and combatants. This is primarily due to the fact that there is no crew restraint. Bids are normally taken from shipyards located on the coast where the ship is homeported.

C. AFSPMP

The AFSPMP was implemented in 1981 for Atlantic Fleet AFSs. The AFSPMP is tailored after, but is not identical to, the MSC maintenance policy. The AFS Phased Maintenance Program Second Formal Evaluation Report explicates six key elements in the AFSPMP [Ref. 16 : pp. I-2,3]. These elements are summarized below.

1. Maintenance Cycle

The Atlantic Fleet AFSPMP five year operating cycle is composed of four, two-or-three month long Selected Restricted Availabilities (SRAs), with approximately twelve months between availabilities. One of the four SRAs in an operating cycle is extended by one month to allow for drydocking. No regular overhauls are scheduled.

2. Prudent Risk

The concepts of reliability centered maintenance and on-condition assessment are utilized to determine what maintenance should be accomplished, thus eliminating most preauthorized work items. Work is scheduled for an SRA or assigned to a shipyard only when there is clear evidence of actual or potential failure and the repairs are beyond the capability of ship's force or Intermediate Maintenance Activities (IMAs).

3. Modernization

The relatively short but frequent SRAs require a change in the way ship modernization is accomplished. Marginally beneficial alterations are eliminated and the remaining ones are sectionalized, when necessary, so that they may be accomplished over a series of SRAs. This has been called incremental modernization.

4. Port Engineers

Two port engineers are assigned to the three Atlantic Fleet AFSs. The port engineers work directly for the Commander Surface Forces Atlantic Fleet (SURFLANT) auxiliary type-desk officer, and they are responsible for the planning, execution, and evaluation of all maintenance performed on the AFSs [Ref. 4: p. 5]. They must also accomplish machinery condition analysis, the specification of job scope, and recommendations for assignment of work to ship's force, IMA, or SRA.

5. Contract

The AFSPMP uses a cost-plus-award-fee, multi-year, multi-ship contract with a single private shipyard in the homeport. The AFSPMP contract is designed to be a one year contract with four successive one year options that are renewable by the Navy, for a total of five years of overhaul work [Ref. 15: p. 3].

The primary objectives of the contract are to: (1) avoid the requirement to specify an inflexible work list prior to an availability; (2) enable high quality and timely work to be rewarded; (3) allow the crew to remain in homeport during the availability; and (4) provide an opportunity for learning in terms of improved efficiency and familiarity for both the shipyard and ship's force.

6. Prepositioned Material

There are two types of prepositioned material. The first type facilitates a change out (instead of a repair) of equipment during an SRA. The purpose of the second type is to make the spare parts and consumables for several critical systems available to avoid preauthorizing unnecessary work just to insure the presence of the material if it is required during the availability.

D. COMPARISON OF MSC AND AFSPMP POLICIES

The AFSPMP was designed as a derivative of the MSC and commercial maintenance policies. It was recognized that differences in missions, crews, and armament systems would not allow a simple copying of the MSC policy. Although the basic mechanics of the two maintenance policies are the same, there are several major differences. The reader should keep in mind that the terminology used by the two organizations is not quite the same either. Although an SRA technically is not an overhaul it takes as long to accomplish as the MSC overhauls. In addition, the scope of the repair and alteration work, as well as the manday and dollar costs, may be larger for an SRA than for an MSC overhaul.

1. Operating Cycle

Although AFSs still have a nominal five year operating cycle, if one considers each SRA to be an overhaul, then one can define an effective operating cycle. The AFSPMP policy results in an effective operating cycle that is approximately fifteen months long. The equivalent operating cyle for MSC ships is approximately twenty-four months in duration. Thus, the Navy has shortened the effective operating cycle to about sixty percent of that employed by MSC.

2. Port Engineers

Port engineers for the AFSPMP generally do not have the absolute authority that MSC port engineers have. Their role in the depot maintenance planning and execution process is somewhat more limited than it would be in an MSC environment. The port engineers are operating as closely as possible to their MSC counterparts, with the major exception of contracting authority [Ref. 4: p. 4].

3. Maintenance Planning

This process is still more complex for the Navy than it is for MSC. The Navy has had to adapt their preauthorization approach to overhaul planning to the on-condition assessment approach used by MSC. The Navy still uses the same basic planning structure, but many of the components have been revised to incorporate port engineers and on-condition assessment.

4. Modernization

The Navy does a lot more modernization than civilian or MSC type organizations. As previously indicated in Table I, the Navy may expend as much as four times the resources on alterations. If all of these alterations are necessary, then there may be legitimate reasons for Navy overhauls to cost more than MSC overhauls. The costs of alterations are usually hard to separate from maintenance costs. In addition, some alterations consist of replacing outdated or inoperable equipment with new ones. Although the cost of an alteration may include all of the equipment and labor, it probably does not account for the repair costs that would have been incurred had the equipment been repaired instead of replaced.

E. SUMMARY

This chapter has briefly described the conventional, MSC, and AFSPMP maintenance policies as they apply to the

AFSs. The AFSs, under the conventional policy, were scheduled for overhauls of four months duration and overhaul intervals of fifty-four to sixty months. MSC overhauls are approximately one or two months in duration and are scheduled every other year. In addition, a mid-period inspection is usually performed between the tenth and fourteenth month out of overhaul. During this two to three week period, voyage repairs and American Bureau of Shipping required inspections are completed. The Atlantic Fleet AFSPMP calls for a five year operating cycle composed of four, two-or-three month long Selected Restricted Availabilities (SRAs), with approximately twelve months between availabilities. One of the four SRAs is extended by one month to allow for drydocking. In contrast to the conventional policy, the MSC and AFSPMP policies are based on prudent risk. Reliability centered maintenance concepts are being employed in the AFSPMP. This chapter also compared the MSC and AFSPMP policies since the AFSPMP policy was modeled after the MSC policy. Differences in the operating cycle, the port engineer concept, maintenance planning, and modernization were addressed. The following chapter will develop an evaluation of the AFSPMP.

VI. AFS PHASED MAINTENANCE PROGRAM EVALUATION

The CNO authorized the AFS Phased Maintenance Program (AFSPMP) in 1979 as a five year test effort to (1) modify the AFS overhaul cycle to minimize the duration of depot level maintenance periods in order to facilitate keeping one of three ships forward deployed at all times and (2) test a maintenance plan similar to that employed by the Military Sealift Command (MSC) and commercial shipowners to determine possible benefits to the Navy [Ref. 4: p. 1].

The objective of this chapter is to evaluate the AFSPMP with regard to the two goals stated above. The first section of the chapter will concentrate on the total depot and intermediate level maintenance costs for an Atlantic Fleet AFS for a five year operating cycle under four alternative maintenance policies. These will be used to determine how well the AFSPMP has performed with regard to costs. The second section of this chapter will present several advantages and disadvantages of the AFSPMP in an effort to analyze the benefits of the program. Finally, the third section will attempt to determine how well the AFSPMP has satisfied its original objectives.

A. MANDAY AND DOLLAR MAINTENANCE COSTS

The intermediate and depot level maintenance costs for an AFS under a series of alternative maintenance policies can be used to determine how well the AFSPMP has performed with regard to costs. Cost estimates are made for the following alternative maintenance policies:

(1) FY 75-79 Conventional Maintenance Policy,

(2) FY 81-85 Conventional Maintenance Policy,

(3) FY 81-85 Phased Maintenance Policy, and

(4) FY 81-85 MSC Maintenance Policy.

There are two types of costs that are frequently used to measure the cost of maintenance or repair work: mandays and dollars. Costs are often measured in terms of mandays instead of dollars so that inflation does not have to be accounted for and due to differences in manday costs among private and public shipyards, different locations, etcetera. In this study both manday and dollar costs are determined whenever possible.

The manday and dollar cost estimates for the first policy are used as a baseline and represent the conventional maintenance costs over a five year cycle prior to phased maintenance. The second set of estimates are a projection of the cost of conventional maintenance, as if the AFSs had not entered phased maintenance. It assumes there is a moderate amount of cost growth from one cycle to the next. The estimates for the third policy are projections of the cycle manday and dollar costs of maintaining an AFS under the AFSPMP. Finally, the estimate for the fourth policy represents the dollar costs MSC would incur, if an AFS was transferred to it. This is an important estimate because the AFSPMP was modeled after the MSC policy.

The cost elements considered are Regular Overhaul (ROH), Selected Restricted Availability (SRA), Restricted and Technical Availabilities (RA/TA), Intermediate Maintenance Activity (IMA), and Commercial Industrial Service (CIS). As mentioned in Chapter V, under phased maintenance one of the four SRAs for each ship is extended for drydocking. These SRAs will be referred to as DSRAs.

The primary sources of data for the first three policies were the three program evaluations that were produced by the Naval Sea Systems Command (NAVSEA 911) in conjunction with American Management Systems, Inc. (AMS) [Ref. 16-18]. These reports contain a large quantity of actual manday and dollar cost data for the three Atlantic Fleet AFSs. The data extracted for use in this study is reproduced in Appendix B. The cost data used for the MSC estimate were contained in a letter from the MSC Engineering Officer to Information Spectrum, Inc. The purpose was to provide cost information for use in a study titled <u>Final Report, Civilian Manning of AE, AFS, and AD</u>

Type Support Ships [Ref. 19]. The cover letter and applicable enclosure are also reproduced in Appendix B.

Two approaches were used to estimate the five year cycle costs for each of the first three maintenance policies. The first method for each policy was different and resulted in point estimates only. Method one for the FY 75-79 conventional policy consisted of summing adjusted historical cost data for the three Atlantic Fleet AFSs to determine the average manday and dollar maintenance costs for one AFS. The first method for the FY 81-85 conventional policy consisted of extracting the manday cost estimate made by AMS from the preliminary AFSPMP program evaluation report that was published 30 September 1981 [Ref. 17]. The method one estimates for the FY 81-85 AFSPMP were based on those made by AMS and NAVSEA 911 in the second and third formal AFSPMP program evaluation reports [Ref. 16 and 18]. The IMA and CIS cost projections were made in March 1983 and the SRA/DSRA and RA/TA cost projections in August 1983. Those projections were made approximately halfway through the first AFSPMP five year operating cycle.

The second approach employed a somewhat more complex cost model to aggregate the data. The model was used to make estimates of the total cycle costs and to construct confidence intervals. The first step was to use cost data over several time periods for each AFS to compute the average cost per time period, for each cost element, for each of the three AFSs. The corresponding costs for each of the three AFSs were then averaged to determine the average cost per time period, by cost element, to maintain one AFS. The average five year cycle cost for each cost element was then projected by multiplying the average cost per time period by the number of time periods during which that type of cost would be incurred. The final step was to add the individual cost elements together to estimate the average total five year cycle cost for one AFS. In the actual model each cost element was considered to be a random variable and the Central Limit Theorem (CLT) was used to assert that the distribution of the mean of each of the random variables is approximately normal. The means of these distributions are the average costs per time period to maintain one AFS. The variance for each of the new random variables (representing the mean of the original cost element random variables) is specified by the CLT to be the sample variance of the three average cost per time period values (one for each AFS) divided by three. These random variables were then summed in a two step process to form a total cost random variable, which is also approximately normally distributed. The distribution of the total cost was then used to construct a confidence interval for the total cost. The basic model used to aggregate the various costs and determine the probability distribution of the total cycle cost is developed in Appendix C.

A simple cost aggregation scheme was used to estimate the dollar costs for the MSC policy. Manday estimates and confidence intervals were not possible for the MSC policy due to data limitations. In addition, the cost element structure of the MSC data is not exactly the same as the structure for the other three policies. This problem is explained in greater detail in Appendix E. It does not present a significant problem for this analysis since a rough MSC cost estimate is all that is required.

The source of data, assumptions, and methodology for each of the cost estimates is presented in Appendix E. Dollar costs were converted to constant FY 84 dollars using the escalation factors in Appendix A. The point estimates of the total cycle cost for each of the four alternative maintenance policies are summarized in Table II.

The difference between the estimates produced by method one and the cost model are small. Because of this and the fact that the cost model resulted in an estimate of the variance, all of the remaining discussion of costs for the first three policies will be in reference to those produced by the cost model. A summary of the individual cost elements, based on the cost model for the first three alternative policies, is provided in Table III.

The variances that resulted from the cost model were used to determine ninety-five percent confidence intervals. These intervals should be considered to be approximate due

TABLE II

Atlantic Fleet AFS Five Year Operating Cycle Total Manday and Dollar Depot and Intermediate Level Maintenance Costs

MAINTENANCE POLICY	MANDAYS	FY 84 ($000s)
FY 75-79 CONVENTIONAL		
Method One	68759.3	17387.6
Method Two-Cost Model	69351.2	17486.6
FY 81-85 CONVENTIONAL		
Method One	97203.9	none
Method Two-Cost Model	92859.8	24499.2
FY 81-85 AFSPMP		
Method One	82379.0	29644.3 *
Method Two-Cost Model	83035.4	29869.8 *
FY 81-85 MSC	none	23477.5

* AFSPMP dollar estimates are not in constant FY 84 dollars because the original data consisted of the sum of the actual dollar expenditures. These estimates can be assumed to be lower than they actually would be if they could be converted to constant FY 84 dollars.

to the underlying assumptions of the cost model. Their primary purpose is to gain insight into the differences in the variability of the various alternative policies, not the absolute variance. These point estimates and confidence intervals are best displayed in bar chart form. Figures 2 and 3 present the manday and dollar cost point estimates and the associated confidence limits.

The entries in Tables II and III and the bar graphs in Figures 2 and 3 reveal many interesting things about the costs of the four alternative policies.

TABLE III

Atlantic Fleet AFS Five Year Operating Cycle Manday and Dollar Cost Element Estimates

MAINTENANCE POLICY	MANDAYS	FY 84 $000s	$/MANDAY
FY 75-79 CONVENTIONAL			
ROH	46133.0	12219.8	264.9
RA/TA	14648.4	3708.0	253.1
IMA/CIS	8569.8	1558.8	181.9
FY 81-85 CONVENTIONAL			
ROH	69641.6	19232.4	276.2
RA/TA	14648.4	3708.0	253.1
IMA/CIS	8569.8	1558.8	181.9
FY 81-85 AFSPMP			
SRA/DSRA	66419.4	26215.8	394.7
RA/TA	7734.0	1854.0	239.7
IMA	5368.0	950.0	177.0
CIS	3514.0	850.0	241.9
FY 81-85 MSC			
SCHEDULED DEPOT		12995.0	
UNSCHED DEPOT		10482.5	

Note: 1. AFSPMP policy costs are not in FY 84 dollars as discussed in Table II.
2. The costs for the first three policies are based on the cost model.
3. The choice of cost elements and basic assumptions are detailed in Appendix E.

1. Total Cycle Cost

Table II and Figure 2 clearly show that the projected AFSPMP cycle manday costs for a single AFS are smaller than the projected costs of conventional maintenance had the phased maintenance program not been implemented. In contrast to this, the projected AFSPMP cycle dollar costs are greater than the corresponding conventional maintenance costs. In addition, the dollar

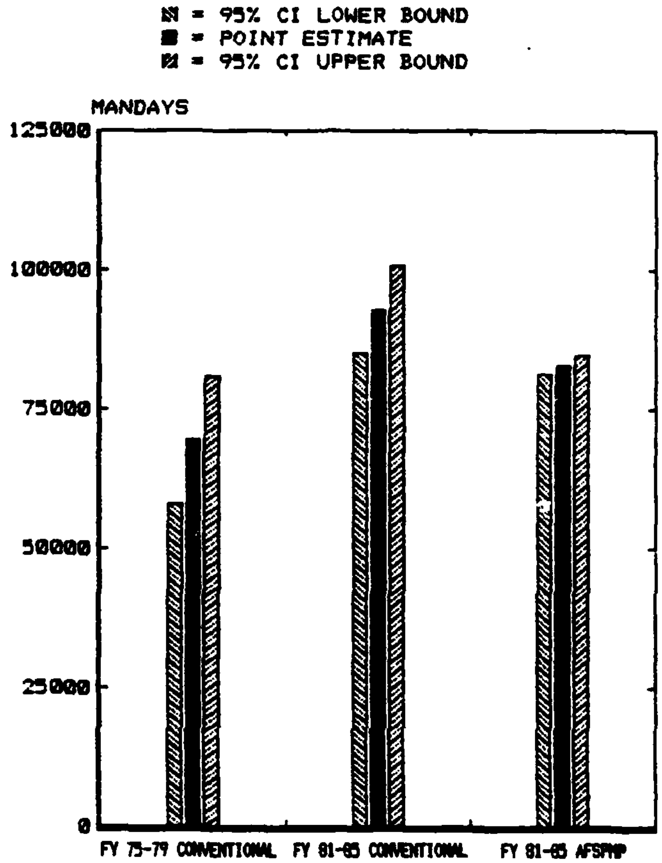

Figure 2 Manday Point Estimates and CIs

cost difference is probably understated in Table II and Figure 3 due to the fact that the AFSPMP costs are not in FY 84 dollars. If the AFSPMP dollar costs could be converted to FY 84 dollars they undoubtedly would be larger than the numbers displayed. On the other hand, it is possible that the cost elements for the two policies are not exactly the same. For example, NAVSEA[1] has suggested

[1]Telephone conversation with Mr. Kenneth Jacobs, of NAVSEA (911), on 31 January 1984.

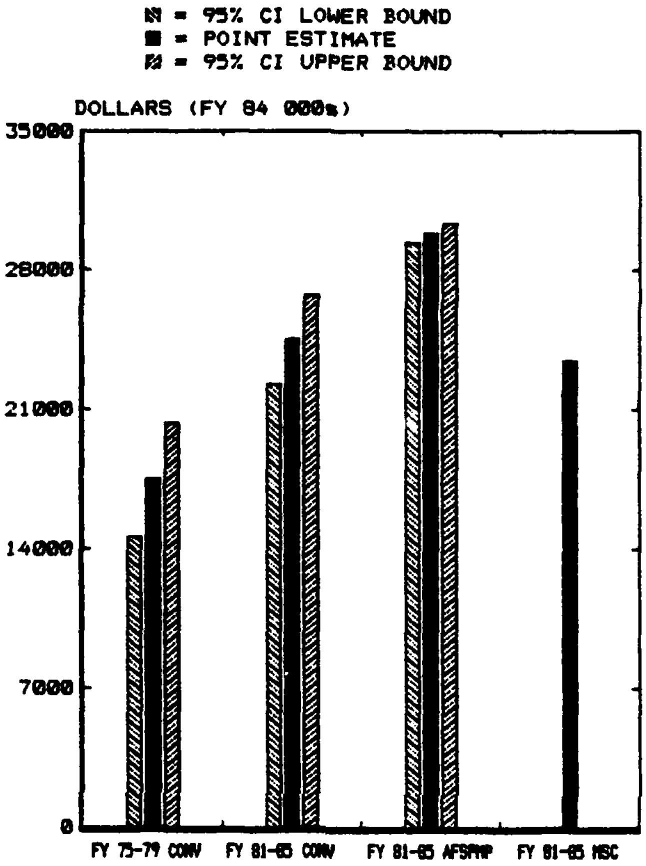

Figure 3 Dollar Point Estimates and CIs

that the AFSPMP costs are more visible. In particular, NAVSEA has indicated that some of the planning for Fleet Modernization Program (FMP) ship alterations (SHIPALTs) that used to be performed by the Supervisor of Shipbuilding, San Francisco, is now accomplished as part of the SRA by the shipyard. As a result of these uncertainties the cost estimates in this chapter should be viewed as rough approximations. Some of the possible reasons for the incongruity in the manday and dollar costs are discussed in the next paragraph.

2. Dollars per Manday

The final column of Table III was produced by dividing each dollar estimate by the corresponding manday estimate. The total cost per manday for the AFSPMP appears to be significantly larger than for the conventional maintenance policy. This is an important result because of the extent to which the Navy relies on manday costs for decision making. If the dollar costs are not monotonically related to the manday costs and one desires to stabilize or reduce the dollar costs of maintenance as well as the manday costs, then the two types of costs must be considered simultaneously.

The difference in the cost per manday is due entirely to the SRA and DSRA cost elements. Table III indicates that the AFSPMP rate for this cost element is at least $394.7 per manday and the conventional rate is $276.2 per manday. There are several possible reasons for such a large difference.

One possible reason for this difference would be that between the FY 75-79 and the FY 81-85 conventional cycles the cost per manday increased more rapidly than historical data would suggest. This would result in under-estimated FY 81-85 conventional policy dollar costs. In 1981 American Management Systems, Inc. estimated that in FY

84 the dollar per manday rate for private shipyards on the East Coast would be 276 to 297 dollars per manday [Ref. 17: p. A-39]. Those estimates are based on an exponential trend line and the conventional policy rate in Table III is within this range. In addition, the Ships Maintenance and Modernization Division of the Office of the Deputy Chief of Naval Operations for Logistics (OP-43) has indicated that $276.2 per manday is not an unreasonable number.[2]

A second possible reason is that the productivity of the labor force used in the AFSPMP SRAs may be greater than for conventional ROHs. The observation that dollar costs can increase while mandays decrease is intuitive. One way to reduce mandays and still get the job done is to hire the most qualified personnel possible and give them good tools and equipment to use. Well trained and equipped workers can accomplish much more work in a given number of mandays than poorly trained and equipped personnel. The managers of the AFSPMP have been very concerned with keeping the number of mandays of depot level maintenance below the CNO-imposed cap of 78000 mandays per ship per cycle [Ref. 16-18]. Thus, in their attempts to minimize mandays, the actual dollar costs may not have been adequately considered. In terms of the formal optimization problem in Chapter IV, the managers may not have properly

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[2]Telephone conversation with Commander J.F. Hamma, of OP-43, on 28 February 1984.

weighted the dollar costs in their personal subjective MOEs.

A third possible reason for such a large difference between the two rates involves shipyard utilization.[3] The AFS SRAs are accomplished at the Jonathan Corporation shipyard and are the primary source of revenue for that shipyard. There has not been an AFS in the shipyard continuously. Therefore, overhead expenses may be greater on a per ship basis. As more ships are put into phased maintenance the shipyard will become more level-loaded, thereby spreading the overhead costs among more availabilities and ships. This would not have been a problem if the SRAs had been accomplished at a large shipyard where there were many other contracts as well. The extent to which this has affected the AFSPMP dollar cost projections in this study could not be determined due to lack of detailed cost data.

3. MSC Maintenance Projection

Another interesting result is the FY 81-85 MSC maintenance policy cost estimate. The cost data used for this estimate were extracted from a letter from the MSC Engineering Officer to Information Spectrum, Inc. The purpose was to provide cost information for use in a study titled Final Report, Civilian Manning of AE, AFS, and AD Type Support Ships, dated 5 April 1983 [Ref. 19]. The set

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[3]Telephone conversation with Commander J.F. Hamma, of OP-43, on 28 February 1984.

of cost data and the calculations made for this study are contained in Appendix E.

Figure 3 shows that the AFSPMP dollar cost is somewhat larger than the MSC cost. This is understandable due to the fact that the Navy does not have extensive experience with progressive maintenance policies and because the AFSPMP and MSC policies are not identical.

The surprising result is that the MSC policy cost estimate is nearly the same as the projected conventional maintenance cost. This is significantly different from the figures in Table I which indicate the Navy's cost used to be three or four times as large as MSC.

The AFSPMP is modeled after the MSC policy. If circumstances have changed such that MSC maintenance costs are now of the same relative magnitude as the Navy conventional policy, then perhaps the Navy should not move toward the progressive MSC policy. This is certainly an area in which more research must be done.

4. <u>Cost Variance</u>

The variances associated with the AFSPMP, as indicated by the lower and upper confidence limits in Figures 2 and 3, are clearly much smaller than for the conventional policy. A small variance in costs is very beneficial for planning maintenance and, since it is a benefit, will be discussed in more detail in the next section of this chapter.

5. Sensitivity of Total Cost to Cost Elements

Table III summarizes the cost element estimates for each of the four alternative maintenance policies. The FY 81-85 conventional and AFSPMP ROH/SRA cost elements account for seventy-five to eighty-eight percent of the total cycle cost, whether the cost is measured in mandays or dollars. This implies that variations in the cost of scheduled depot level maintenance will influence the total cycle cost much more than any of the remaining cost elements.

B. AFSPMP BENEFIT ANALYSIS

The primary quantitative and qualitative advantages and disadvantages of the AFSPMP over the conventional maintenance policy are presented below.

1. Advantages

a. Manday Costs

Table II and Figure 2 clearly indicate that the manday costs of maintaining an AFS under the AFSPMP are approximately ten percent less than they would be under conventional maintenance. This is beneficial because the number of mandays of depot level maintenance available to the Navy is finite.

b. Unscheduled Depot Maintenance

As one can see in Figures 4 and 5 the projected AFSPMP unscheduled depot level maintenance is approximately fifty percent of that projected for the conventional

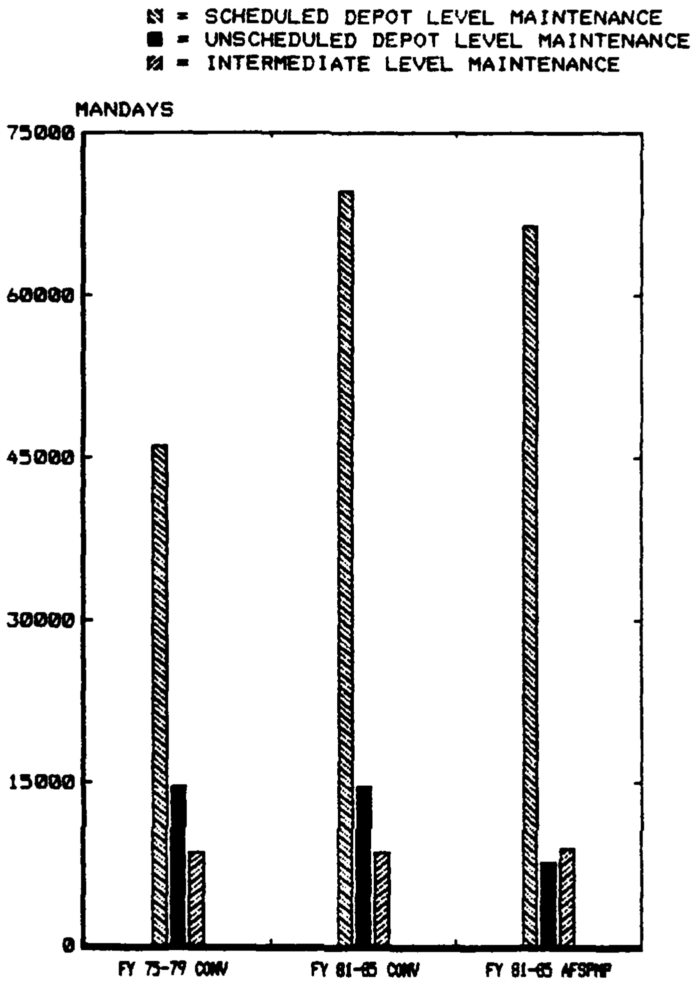

Figure 4 Manday Cost Element Distributions

policy. This implies that the AFSs, under phased maintenance, have experienced fewer casualties that require depot level maintenance, indicating a general improvement in material condition. The end result is that the AFSPMP may lead to more reliable ships and fewer changes in operational schedules.

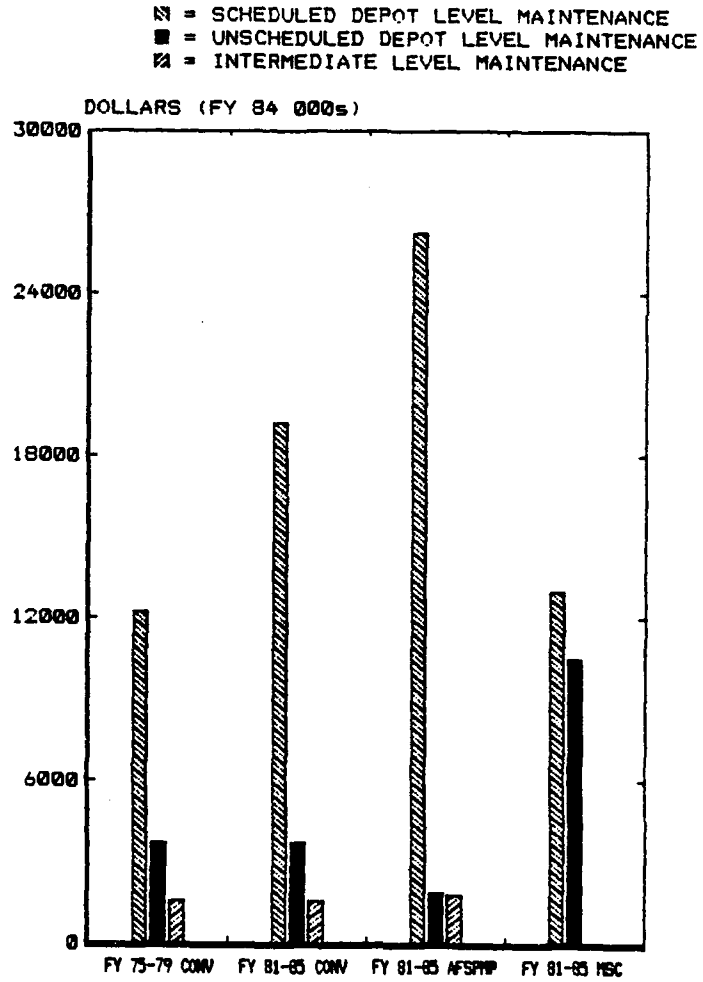

Figure 5 Dollar Cost Element Distributions

c. Cost Variance

Figures 2 and 3 show that the AFSPMP and conventional policy maintenance costs differ greatly in variability. The confidence intervals for both the manday and dollar costs are much larger for the conventional maintenance policy. The source of the reduced variability for the AFSPMP is probably a combination of two factors.

First, it is not unreasonable to expect that the costs shorter, more frequent availabilities are inherently ea to control than for the long infrequent regular overhau The second likely reason is the use of port engineers, which will be discussed separately. Irrespective of the reasons, the reduced variability implies that the AFSPM maintenance costs may be easier to budget and plan for would have been possible under the conventional mainten policy.

d. Availability

The AFS Phased Maintenance Program Third Fo Evaluation Report [Ref. 18: p. 3] was used as the sourc information concerning AFS downtime and availability.

The actual and projected downtime for the A is displayed in Figure 6. This figure shows that the AF are spending much less time in Restricted Availabilitie and that the overall downtime thus far in the five year cycle is about the same as it would have been under pha maintenance.

Figure 7 compares the overall availability the AFSs under the two maintenance policies. Halfway through the first AFSPMP cycle the availability is abou the same as it was under conventional maintenance. The overall availability is projected to be seventy-two per for the AFSPMP as opposed to sixty-eight percent for conventional maintenance. This modest four percent

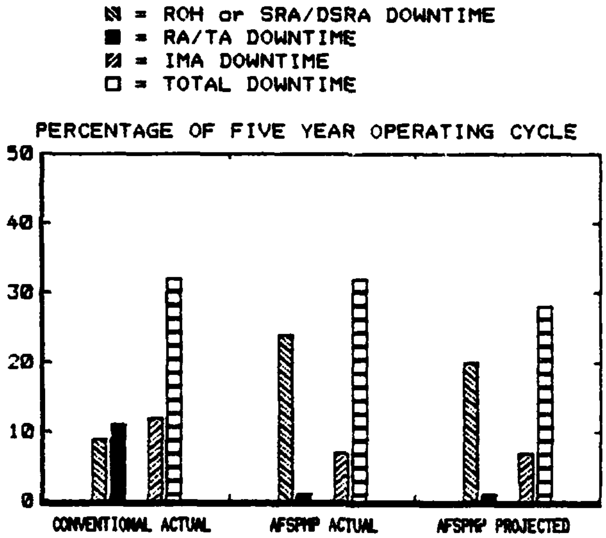

Figure 6 Atlantic Fleet AFS Downtime

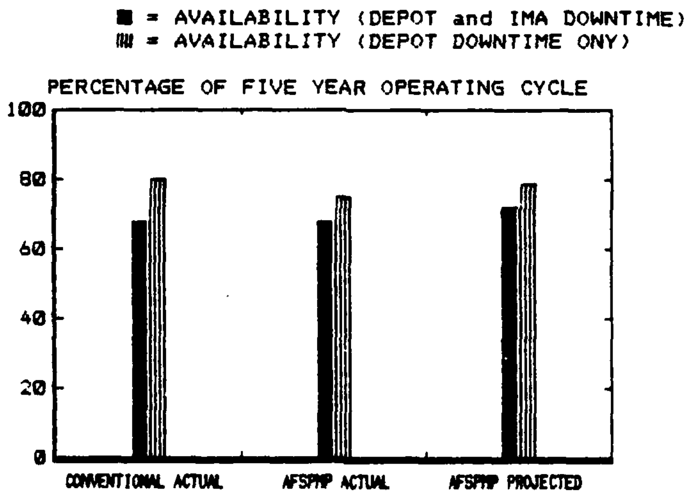

Figure 7 Atlantic Fleet AFS Availability

improvement equates to approximately two and one-half additional months that an AFS could be used operationally during a sixty month cycle.

e. Mobility

One may argue that if the Navy must mobilize its forces then the AFSPMP has a significant advantage over conventional maintenance. This is because at any given point in time the maximum time out of SRA for each of the Atlantic Fleet AFSs would be twelve months or less. If the AFSs were under conventional maintenance this maximum time could be as large as forty-eight months. In addition, the maximum time to make all three AFSs available would not exceed four months, whereas a ship that had entered a regular overhaul would probably require much more time. The implication is that at any random point in time the AFSs would, in general, be in a higher state of material readiness under the phased maintenance program.

f. Schedule Stability

In recent years it has not been uncommon for ships to remain in overhaul well past their scheduled end dates. The effects of a ship coming out of overhaul several months late can be dramatic. The schedule of the particular ship obviously changes and in many cases the schedules of other ships in the parent squadron or organization are also affected. Even when ships complete their regular overhaul on time it is not uncommon for them to have serious material problems throughout the following year. In addition to solving those problems, intensive training must be accomplished to return the ship to a high state of readiness.

The point is that there is a significant amount of uncertainty surrounding any regular overhaul. In the past it has not been uncommon for one ship to take another ship's operational commitments. Last minute changes in a schedule are detrimental to morale and also can result in an unfair sharing of deployments and other commitments. Such was the case for the three Atlantic Fleet AFSs prior to the implementation of the AFSPMP. Since the AFSs started phased maintenance, all depot level availabilities have been completed on time and all commitments have been met [Ref. 18: p. 5].

g. Material Condition

The Navy presently does not have a precise and reliable way to quantitatively measure the material condition of a ship. Many factors are involved and there is no general agreement as to what the measure of effectiveness should be. Two commonly used proxies for the material conditon are the number of C-3 and C-4 Casualty Reports (CASREPs) per unit time and the number of discrepancies reported by the Board of Inspection and Survey (INSURV Board). The extent to which a maintenance policy impacts upon these two measures is very difficult to determine because there are many other factors that significantly influence them. These include, but are not limited to, the extent and nature of ship operations, the training of equipment operators, the training of preventive and corrective maintenance personnel and the extent to which this maintenance is accomplished, and the attitude of the ship's officers and senior enlisted personnel.

Only one INSURV has been completed since the implementation of the AFSPMP and it was too soon after implementation for the AFSPMP to have a substantial effect. All three Atlantic Fleet AFSs are scheduled for INSURVs during FY 84 and 85, so a detailed analysis will be possible at about the same time the first five year cycle comes to an end.

The AFSs averaged 3.0 C-3 and C-4 CASREPs per quarter prior to the implementation of phased maintenance. The occurrence of these for mission essential equipment averaged 0.6 per quarter. Since implementation the average number of C-3 and C-4 CASREPs has dropped to 2.1, but the number of mission essential equipment CASREPs has increased to 0.8 [Ref. 18 : p. 11]. The only conclusion that can be reached from these statistics is that the material condition of the AFSs has not been affected severely by the AFSPMP.

There are, however, qualitative reasons to believe that the material condition of the AFSs is slowly improving. Comments made by Commander Service Group Two and the Commanding Officers of some of the AFSs lead to this assertion [Ref. 18: p. 14].

h. Training

Regular overhauls lasting six or more months typically make it very difficult for the ship's crew to remain in a high state of training readiness. The turnover of personnel during an overhaul can be thirty percent or higher. Once the ship completes the overhaul and becomes operational again it takes a long time, perhaps six months or more, to regain the level of training and operational readiness that existed prior to the overhaul.

The AFSPMP has a strong advantage in this area. The SRAs are only three or four months long; therefore, the continuity in training is much easier to maintain.

i. Port Engineer Concept

The port engineer concept is a key element of the AFSPMP and appears to be working well. The port engineer helps to fill the void that exists between the ship's crew and the various shore-based organizations. The Naval Sea Systems Command (NAVSEA 911) reported in their third formal evaluation that

> "The ship, with the port engineer available as a technical consultant, is able to make wiser repair decisions. With the port engineer on site as a TYCOM representative, the supervisor (SUPSHIPS) is able to more efficiently monitor the contractor and handle growth work. The shipyard benefits from the port engineer's commercial experience. The port engineer talks

details with shipyard specification writers and production foremen, providing an important communications link that enhances SRA productivity. The port engineer often challenges shipyard labor and material estimates. Furthermore, the port engineer, as a direct TYCOM representative, strives to adhere to CNO-imposed manday constraints. He brings the TYCOM maintenance staff right to the waterfront." [Ref. 18: pp. 10-11]

2. Disadvantages

a. Dollar Costs

As previously discussed, the AFSPMP appears to cost more dollars than the conventional policy. Table II indicates that the additional expense may be twenty percent or more. Although this figure may not be exact, it is a very strong indication that the AFSPMP is not saving any dollars. Further research must be conducted to determine if the AFSPMP dollar costs can be reduced without changing the benefits of the program. If the dollars costs cannot be reduced, the CNO will have to determine if the AFSPMP benefits are worth the additional dollar expense.

b. Flexibility

The frequent but short SRAs constrain the way in which the AFSs can be used operationally. Each ship must undergo a three month SRA following each twelve months of operations. If for some reason the Navy is forced to operate all three ships on an extended basis one or more of the ships will miss an SRA. The effect of this on the AFSPMP program is hard to determine. Due to the multi-ship multi-year contract structure the effect would probably be more dramatic under phased maintenance than it would be under conventional maintenance, where single-ship contracts are negotiated just prior to a specific overhaul. Short of conducting a regular overhaul, it would be hard to recover from a missed SRA. In addition, the maintenance cycle of all of the AFSs would be thrown off schedule.

c. Modernization

The portions of ROHs and SRAs devoted to the accomplishment of ship alterations (SHIPALTs) has led to a backlog of SHIPALTs. This problem is compounded further under phased maintenance because the number of mandays available to perform alterations during a single SRA may be fewer than the number of mandays required for a particular SHIPALT. The backlog and an insufficient number of mandays to complete all of the scheduled SHIPALTs led to a purge of approximately thirty percent of the alterations scheduled for the AFS Fleet Modernization Program (FMP) [Ref. 16: p. V-4]. In addition, the short duration of SRAs led to the accomplishment of SHIPALTs through "incremental modernization." This means that the larger SHIPALTs are broken down into smaller packages, which are accomplished during successive SRAs. The method appears to be effective, but certainly there are costs involved in redesigning the SHIPALTs for accomplishment in small segments. As new SHIPALTs are authorized this should not be a problem because they can be designed for incremental modernization as necessary.

C. ACCOMPLISHMENT OF AFSPMP OBJECTIVES

Now that the primary advantages and disadvantages of the AFSPMP have been discussed, it is possible to attempt to determine if the AFSPMP has been successful in meeting its goals.

1. Availability

The first goal was to minimize the duration of depot level maintenance to facilitate keeping one ship in the Mediterranean at all times. Prior to phased maintenance the three Atlantic Fleet AFSs did not share deployments equally. Although the projected availability of each AFS under phased maintenance is four percent higher than under conventional maintenance, the amount of time spent in depot maintenance facilities is approximately the same. The AFSPMP should, however, be considered to be a success with respect to this first goal because the amount of unscheduled depot level maintenance has decreased and the three ships are able to meet their commitments and share the workload evenly. This was summarized by the Naval Sea Systems Command (NAVSEA 911):

> "A primary reason for adopting the revised schedule for Atlantic Fleet AFSs was to keep one AFS on station in the Mediterranean with the Sixth Fleet at all times. This is now being accomplished without placing undue strain on any Atlantic Fleet AFS. Phased maintenance has brought stability and consistency to LANTFLT AFS

deployment patterns. All SRAs have been completed on-time or early. All operational commitments have been met." [Ref. 18: p. 5]

2. Test MSC-Type Maintenance Policy

The second goal was to test a policy similar to that employed by MSC to determine the possible benefits to the Navy. One should not expect the AFSPMP to be as successful as MSC has been over the years because of the relative inexperience of the Navy in progressive maintenance policies and the differences between the two policies. Some of these differences were discussed in Chapter V.

The preceding sections of this chapter have discussed some of the advantages the AFSPMP has over conventional maintenance. One may conclude that the Navy version of the MSC policy has exhibited attributes that are very beneficial to the Navy. In terms of the MSC policy, at this stage in the first AFSPMP five year cycle there is really only one area that must be questioned--the dollar costs.

Table II and Figure 3 show that the AFSPMP five year cycle will cost approximately twenty-seven percent more than MSC estimates it would have to spend. MSC did not provide any indication of the variance in their estimates, so it cannot be determined if the difference in the dollar cost is statistically significant. In Appendix E the variance of the MSC annual dollar cost was estimated through assumptions of normality and the accuracy of the MSC cost data. It was found that if the annual cost estimate based on MSC data was accurate to within plus or minus fifty percent then the ninety-five percent confidence interval would be (20047.7 to 26907.3). Thus, even if MSC's estimates are poor, their maintenance policy seems to be less expensive than the AFSPMP.

One significant advantage the AFSPMP appears to have over MSC is the cost of unplanned depot level maintenance. Table III indicates that the MSC estimate of unscheduled maintenance is at least five times as large as the estimate for the AFSPMP.

3. Conclusion

There is no question that the AFS Phased Maintenance Program (AFSPMP) has been successful in meeting the objectives that were established at the outset of the program. Since phased maintenance was implemented the following have resulted: the projected AFS availability has risen four percent; the Atlantic Fleet AFS deployment problem no longer exists; the manday cost growth has been stabilized; the material condition of the ships is improving; the ships seem to be more reliable (as indicated by a reduction in unscheduled depot level maintenance); the dollar and manday costs are less variable; and training continuity has been easier to maintain. In general, the

AFSPMP appears to have substantially improved the general Atlantic Fleet AFS situation.

The Navy is, however, paying dearly for these benefits. As indicated in Table II the projected cost of depot and intermediate level maintenance for one AFS for a five year operating cycle is 83,035 mandays and at least $29,870,000 (FY 84). These costs reflect a reduction in the number of mandays and an increase in the number of dollars as compared to the projected conventional maintenance costs. The increase in dollar costs is at least twenty-two percent or $5,385,000 (FY 84) per ship. This implies that the AFSPMP is costing the Navy on the order of one million additional dollars per year per ship. Since the Navy generally does not have enough money to fund all of the programs desired, one must ask the question: Is the phased maintenance program a cost-effective alternative to the conventional maintenance policy for AFSs and for other classes of ships? This question will be addressed in the following chapter.

VII. PHASED MAINTENANCE--A COST-EFFECTIVE ALTERNATIVE TO CONVENTIONAL MAINTENANCE?

Chapter VI concluded that the AFS Phased Maintenance Program (AFSPMP) has met the objectives that were established for it at the outset of the program. It also identified some of the benefits of the AFSPMP and established that the dollar costs of maintaining an AFS under phased maintenance are estimated to be twenty percent more than under the conventional policy.

The purpose of this chapter is to address the larger question: Is the phased maintenance program a cost-effective alternative to the conventional maintenance policy? The mathematical formulation of the Navy overhaul problem presented in Chapter IV will be used in discussing this question. The first section of this chapter will discuss the cost-effectiveness of the AFSPMP as it applies to the Atlantic Fleet AFSs. The expansion of the phased maintenance program will be addressed in the second section.

A. ATLANTIC FLEET AFSs

Although it is impossible to establish the optimality of the AFSPMP it is possible to evaluate it against the conventional policy. The purpose of doing this is to determine if the Navy is better off with phased maintenance than it would have been under the old policy. Two policies, therefore, must be compared: the FY 81-85 conventional policy and the FY 81-85 phased maintenance policy.

The real question as to which solution is "better" rests in the value of the MOE for each of the two policies. In fact, this is how Navy decision makers deal with these types of problems. They have subjective MOEs that are used to evaluate the various trade-offs that characterize the available alternatives. If the MOE is properly defined it will account for all of the possible trade-offs. For example, the marginal utility of having a specified number of additional units of reliability would be worth a certain additional number of dollars.

A simple approach to illustrate how the AFSPMP can be compared to the conventional policy is to use a linear MOE based on deviations from the goals set by the decision makers (DMs). Many analytical models in resource allocation in hierarchical multi-level planning systems employ this type of objective function [Ref. 20].

The constraints in Chapter IV can be viewed as the goals in this problem. If the goals are established at the ship level then the primary goals in the formulation are $Bo = BT/3$, $Do = DT/3$, $Io = IT/3$, CMOo, CMBo, AVo, CAo, TRo, SCHo, Ro, FMPo, and LVo. These variables were defined in Chapter IV on page 34.

AD-A140 967 AN ANALYSIS OF THE ATLANTIC FLEET AFS PHASED MAINTENANCE PROGRAM(U) NAVAL POSTGRADUATE SCHOOL MONTEREY CA S C ROWLAND MAR 84 2/2

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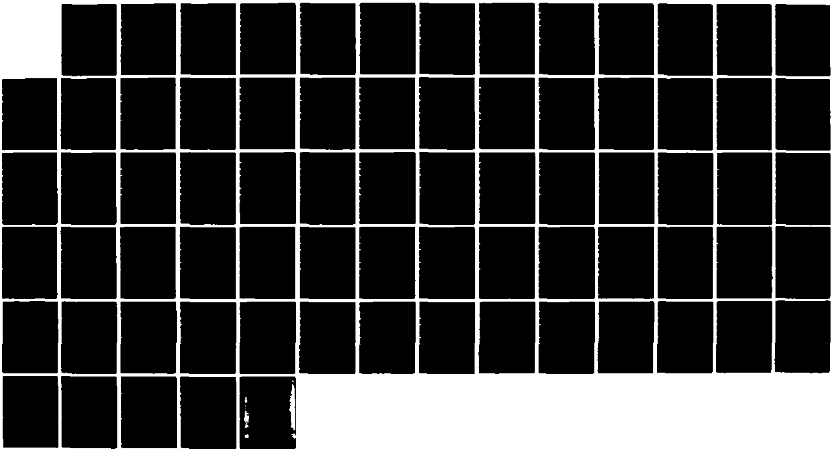

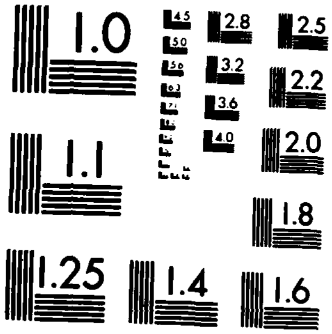

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

Let Yk(+) be a vector representing the amount the kth element exceeds the established goal and Yk(-) be the amount the kth element falls short of its goal. Then, if Wk(+) is a vector representing the decision makers' weights for the Yk(+) deviations and Wk(-) the weights for the Yk(-) deviations, the objective function of the formal optimization problem can be rewritten as:

$$\text{Minimize MOE} = Wk(+)*Yk(+) + Wk(-)*Yk(-).$$

Assumptions about the goal levels and weights must be made in order to continue this illustration. Suppose the DMs have set the goals indicated in Table IV. These goals were derived from the following information. Quantitative information concerning Bo, Do, Io, and AVo was presented in Chapter VI. The cost model estimates are used in this analysis. The dollar goal Bo is assumed to be the dollar cost of depot and intermediate maintenance for an AFS for the FY 75-79 conventional maintenance policy. The goal for the total depot level manday budget Do and the intermediate level manday budget Io are also for that policy. The availability was 68 percent under conventional maintenance and is projected to be 72 percent under the AFSPMP [Ref. 18: p. 3]. Assume that 70 percent, the average of the two, is the AVo goal. The discussion of the benefits of the AFSPMP in Chapter VI revealed that the reliability of each AFS appears to have improved as well as the overall training. The reliability Ro and training TRo goals in

Table IV are assumed to be 90 percent. The R and TR values for the two policies are based on the assumption that the AFSPMP has met the goal and that it was a 10 percent increase over the conventional policy. None of the other constraints are included because data for those variables were either limited or not available. Casualty Report (CASREP) information was not included because the results presented in Chapter VI were not conclusive.

TABLE IV

Example AFSPMP and Conventional Maintenance Policy Goal Deviations

ITEM	GOAL	FY 81-85 CONV	FY 81-85 AFSPMP	CONV Yk(+/-)	AFSPMP Yk(+/-)
Bo	17486.6	24499.2	29869.8	7012.6(-)	12383.2(-)
Do	60781.4	84290.0	74153.4	23508.6(-)	13372.0(-)
Io	8569.8	8569.8	8882.0	0	312.2(-)
AVo	70	68	72	2 (-)	2 (+)
Ro	90	80	90	10 (-)	0
TRo	90	80	90	10 (-)	0

The values in Table IV can now be plugged into the MOE for each of the policies under comparison. Letting MOEc be the MOE for the FY 81-85 conventional policy and MOEa be the MOE for the FY 81-85 AFSPMP, the equations are:

MOEc = 7012.6*W1(-)+23508.6*W2(-)+2*W4(-)+10*W5(-)+10*W6(-)

and MOEa = 12383.2*W1(-)+ 13372*W2(-)+312.2*W3(-)+2*W4(+).

The next thing that must be accomplished is the determination of weights, which specify the decision makers' preferences and trade-offs. The weights must contain a factor representing the overall importance of the particular attribute as well as a scaling factor to account for the differences in activity levels.

The last three weights are all based on the same scale so they will be resolved first. Assume that the DMs have decided that failure to achieve the goal for availability and reliability are equally important, thus establishing that $W4(-) = W5(-)$. Furthermore, assume that the reward for achieving an excess of availability is weighted one-half of the penalty for failing to achieve the goal. This implies that $W4(+) = -W4(-)/2$. Also assume that training is considered only one-half as important as availability, resulting in $W6(-) = W4(-)/2$. This is not unreasonable because a trained crew cannot complete a mission if their ship cannot get underway. Likewise, if the crew is not properly trained to use the ship it will not be very effective even though the ship can get underway.

Assume the DMs believe that mandays of depot level work are one-half as important as dollar costs, since they feel the pressure of dollar constraints more than manday constraints. A correction must be made for the difference in levels; the manday goal is 3.5 times as large as the dollar goal. The resulting relationship between the weights is then $W1(-)=2*3.5*W2(-)$. Also assume that intermediate level mandays are only one-half as important as total dollar costs. Since the dollar goal is two times larger than the intermediate maintenance manday goal the relationship is W1(-) = W3(-).

Similar terms in the two MOE equations can now be combined, resulting in:

$$MOEc = 10371.0*W1(-) + 17 * W4(-) \text{ and}$$

$$MOEa = 14605.7*W1(-) - 1 * W4(-).$$

Since the objective function is a minimization, the AFSPMP will be evaluated as being better than conventional maintenance if MOEa < MOEc, or MOEa - MOEc < 0. This condition can be used to determine the critical point for the relationship between the availability and dollar weights. If

$$MOEa - MOEc = 4234.7*W1(-) - 18*W4(-) < 0, \text{ then}$$

$$W1(-)/W4(-) < 18/4234.7 = .00425 \text{ implies that the}$$

AFSPMP is better than conventional maintenance. So, if the DMs assign dollar and availability weights such that the ratio is less than .00425, the AFSPMP will have a smaller MOE value than the conventional policy and hence will be closer to the optimal solution.

One way to evaluate the ratio above is to consider the total depot and intermediate level dollar cost of an AFS over a five year operating cycle. The total dollar cost for the FY 81-85 conventional policy was estimated to be $24499.2 (FY 84 000s). Since there are 100 percentage points of availability during a five year cycle the dollar cost is $245.0 per percentage point. This can be used to correct for the difference in activity levels. If one then assumes that availability and dollar costs are of equal importance the result is:

$$W1(-) = W4(-)/245.0 \text{ or } W1(-)/W4(-) = .0041.$$

Although this ratio is only slightly smaller than .00425 it implies that given the weighting assumptions in the preceding paragraphs the AFSPMP is better than the conventional maintenance policy. This outcome is somewhat sensitive to each of the assumed weights but the relationship between the availability and cost weights is the driving factor.

Notice that only the depot and intermediate level costs were considered in the final scaling of weights. If one were to include the prorated cost of procurement and ownership of an AFS for a five year operating cycle the ratio would be much smaller. For example, assume that an AFS cost $300000 (FY 84 000s) to procure and that it has a lifespan of thirty years. The resulting prorated cost for a five year cycle is $50000 (FY 84 000s). Information Spectrum, Inc. estimated the annual total operations and maintenance economic cost to the Department of Defense for one AFS to be $14670 (FY 82 000s) [Ref. 19: p. 66]. The economic cost in FY 84 dollars is $15853 (FY 84 000s) annually or $79265 (FY 84 000s) over a five year operating cycle. The total cost of procurement and ownership over a five year operating cycle is then estimated to be $129265

(FY 84 000s). Making the same assumptions as above, W1(-)/W4(-) = .0008, which is much smaller than the critical value.

Working back the other way one can determine the relative level of importance that must be assigned, based on the total costs, to conclude that the AFSPMP is better than conventional maintenance. If X is the multiplier representing the importance of dollars over availability and a scaling factor of 129265/100 = 1292.6 is introduced to account for different activity levels, then W1(-) = X*W4(-)/1292.6. Now,

$$W1(-)/W4(-) = X/1292.6 = .00425 \Rightarrow X = 5.5.$$

Therefore, if the DMs weight the dollar cost of maintenance more than 5.5 times as important as ship availability, they will reach the conclusion that the conventional policy is better. In contrast to this, if the weight is less than 5.5 the conclusion will be that the AFSPMP is better than conventional maintenance. Finally, if the weight is exactly 5.5 the DMs will be indifferent to the two policies.

The general conclusion that can be reached from this simple linear MOE model is that there is good reason to believe that the AFSPMP is better than the conventional maintenance policy despite the fact that the dollar costs are estimated to be approximately twenty percent higher.

The next section of this chapter addresses the expansion of the phased maintenance program.

B. OTHER CLASSES OF SHIPS

Although the AFSPMP appears to be a good alternative to the conventional maintenance policy, much caution should be observed in applying it to other classes of ships.

1. Auxiliary and Amphibious Ships

The phased maintenance program is in the process of being expanded to include several classes of auxiliary and amphibious ships. Table V shows the implementation fiscal year for each of the classes involved. The classes of ships

TABLE V

Phased Maintenance Program Expansion

SHIP CLASS	IMPLEMENTATION (L/P)
AFS	81/83
AOR	84
AO 177	83/84
AE	86
AOE	85/86
LST	86/85
LPH	85
LPD	88
LSD	86

Note : Atlantic/Pacific Fleet implementation dates are indicated where different.

[Ref. 21]

in Table V include more than eighty ships in the active Atlantic and Pacific Fleets, indicating how extensive the phased maintenance program will be in just a few years. The decision to expand the phased maintenance program was based largely on the early results of the AFSPMP. The third formal program evaluation stated,

> "The potential for exportation of the phased maintenance concept continues to be great. However, as pointed out in the previous report, strict adherence to the proven model is essential. Deviations must be carefully assessed." [Ref. 18: p. 25]

Decisions concerning the expansion of the phased maintenance program should account for several important possible problems.

a. AFSPMP Test

One of the primary objectives of the AFSPMP was to test a maintenance policy similar to that employed by MSC. The phased maintenance program for Atlantic Fleet AFSs has essentially been an experiment and this fact must be kept in mind in evaluating the results. The variance of the cost estimates and other statistics must be considered very carefully. In addition, as discussed in Chapter IV, experiments tend to be artificial and the results may be biased due to the fact that people involved in experiments do not necessarily conduct themselves as they would in a non-test environment.

b. Ship Differences

There is no guarantee that what works for one class of ships will work for another. In terms of the problem formulation in Chapter IV, the constraints of the optimization problem could be much different for the various classes of ships. The engineering and operational characteristics of the ship classes identified in Table V are generally not the same as those of the AFSs. Some of these differences are briefly discussed below.

The AFSs have three boilers as opposed to the two that characterize most auxiliary and amphibious ships. The missions of the various classes of ships are also dissimilar, resulting in differences in their basic construction: the AFSs have large storerooms for cargo; the AORs, AOEs, and AOs have large tanks for carrying fuel; the LSDs and LPDs have large floodable well decks; and the LPHs are helicopter carriers with full flight decks. There are also considerable differences in the communications and weapons systems installed in the various classes of ships.

The operational uses of these ships also vary significantly and the deployment patterns are not all the same. In fact, the deployment patterns of ships of the same class may be different, depending on whether they are in the Atlantic or Pacific Fleet. The AFSs, like many of the auxiliary and amphibious ships, are usually scheduled for standard six month long deployments. This is not true for the auxiliary ships that are assigned to specific carrier battle groups. Their deployments usually last longer and are more variable in length than the AFSs.

c. System Management

The number of people per ship managing the phased maintenance program is likely to decrease as more ships are added to the program. This means that management of the system may become more difficult with the possible result of reducing the effectiveness of the program. What works on a small scale does not always work on a large scale. Monitoring the effectiveness of the phased maintenance program will also be much harder to accomplish due to the sheer volume of information that must be processed.

2. Frigates, Destroyers, and Cruisers

Expansion of the phased maintenance program to include frigates, destroyers, and cruisers has also been considered. These ships are so much different from the auxiliary and amphibious ships that additional thought must be given to any change in their maintenance policy.

These ships have large weapons suites, making them considerably more electronic intensive than the auxiliary and amphibious ships. The efficacy of the phased maintenance program in adequately dealing with sonars, gun and missile systems, etcetera has yet to be proven. In addition, the configuration of the engineering plants is quite variable. Some of the ships have two boilers and one shaft, others have four boilers and two shafts, and then there are the gas turbine frigates and destroyers.

The Navy has had some experience in progressive maintenance policies with the FFG-7 class of frigates. However, these ships were designed with this type of maintenance in mind, so the results may not easily be applied to the situation at hand. The Navy has implemented phased maintenance for the Naval Reserve FF-1052s and after one SRA the program appears to be working smoothly. This program should be very useful in helping to determine if phased maintenance is a good alternative to the conventional policy for other frigates, destroyers, and cruisers. In addition, the auxiliary ships under phased maintenance that are tied to battle groups may provide useful information regarding the compatibility of phased maintenance with the deployment patterns of these types of warships.

VIII. SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

A. SUMMARY

The primary objective of this thesis has been to determine if the AFS Phased Maintenance Program (AFSPMP) has been successful in meeting its goals and if it is a cost-effective alternative to the conventional maintenance policy for the Atlantic Fleet AFSs. A secondary objective was to examine several aspects of the expansion of the phased maintenance program.

The evolution of the thorough overhaul concept, which forms the basis for the conventional maintenance policy, was described in Chapter II. This policy resulted from the desire of senior military personnel to improve the material condition of the fleet. The end result was that overhaul repair work was determined largely on the basis of risk avoidance and preauthorization. Risk avoidance is characterized by the inclusion of "insurance items" in the overhaul package. These are items for which there is no current indication that repair work will be needed, but for which it is believed repair work is needed to ensure the ship will be able to operate reliably during its operational cycle. Preauthorization of repair work resulted primarily from the long planning process that is inherent in the conventional policy.

Chapter III reviewed several pertinent studies that strongly indicate the Navy may be able to find a maintenance policy better than the conventional one. Those studies concluded that, in general, the Military Sealift Command (MSC) is able to maintain comparable ships at a significantly lower cost than the Navy can. One General Accounting Office (GAO) report recommended that the Navy move away from insurance repairs toward the concept of reliability centered maintenance (RCM). The basic principle of RCM is to perform only those maintenance tasks that are necessary to maintain designed levels of safety and reliability.

Chapter IV briefly examined the problem of finding an optimal strategy for maintaining ships in a high state of readiness without incurring unreasonable costs. A very general formulation of the optimization problem was presented to aid in the discussion of the complexity of the problem. The problems involved in determining an adequate measure of effectiveness and the mathematical intervariable relationships were also addressed. Chapter IV also reviewed several approaches that have been used to investigate simplified versions of the general overhaul problem. The conclusion reached was that the Navy currently has only one method to reliably evaluate alternative maintenance policies--implement a trial maintenance policy and analyze the results. The Navy authorized such a trial maintenance policy for AFSs in 1979 and called it the AFS Phased Maintenance Program (AFSPMP).

Chapter V briefly described the conventional, MSC, and AFSPMP maintenance policies as they apply to the AFSs. The AFSs, under the conventional policy, were scheduled for overhauls of four months duration and overhaul intervals of fifty-four to sixty months. MSC overhauls are approximately one or two months in duration and are scheduled every other year. In addition, a mid-period inspection is usually performed between the tenth and fourteenth month out of overhaul. During this two to three week period voyage repairs and inspections required by the American Bureau of Shipping are completed. The Atlantic Fleet AFSPMP calls for a five year operating cycle composed of four, two-or-three month long Selected Restricted Availabilities (SRAs), with approximately twelve months between availabilities. One of the four SRAs is extended by one month to allow for drydocking. In contrast to the conventional policy, the MSC and AFSPMP policies are based on prudent risk. Reliability centered maintenance concepts are being employed in the AFSPMP. Chapter V also compared the MSC and AFSPMP policies, since the AFSPMP policy was modeled after the MSC policy. Differences in the operating cycle, the port engineer concept, maintenance planning, and modernization were also addressed.

The costs of maintaining an average Atlantic Fleet AFS over a five year operating cycle were estimated for each of four alternative maintenance policies: (1) FY 75-79 conventional policy; (2) FY 81-85 conventional policy; (3) FY 81-85 AFSPMP policy; and (4) FY 81-85 MSC policy. Both manday and dollar costs were estimated whenever possible. These costs were used in Chapter VI as part of an evaluation of the AFSPMP. The cost estimates revealed that, although the manday cost of depot and intermediate level maintenance has decreased by ten percent with the implementation of phased maintenance, the dollar cost has risen approximately twenty percent. In addition, the dollar estimate for the MSC policy is nearly the same as the projected conventional maintenance costs. This was surprising since for many years MSC's costs were reported to be one-third to one-fourth those of the Navy. In addition, the Navy appears to have reduced the cost of unscheduled depot level maintenance by fifty percent through phased maintenance. Another interesting result was that the estimated variance of the AFSPMP costs was much smaller than for the conventional policy. The reduced variability implies that the AFSPMP maintenance costs may be easier to budget and plan for than would have been possible under the conventional maintenance policy.

Some of the observed advantages and disadvantages of the AFSPMP were also presented. The most important advantage concerns the availability of the AFSs for fleet operations. The AFS availability is estimated to be four percent greater under phased maintenance than it was during the last conventional maintenance policy five year cycle. In addition, the AFSs have been able to meet all of their commitments with an equal sharing of deployments. The material condition of the ships, training, and the port engineer concept were also discussed. The program evaluation in Chapter VI resulted in the conclusion that the AFSPMP has met the goals that were established for it at the inception of the program. In essence, the goals of the program were to stabilize Atlantic Fleet AFS deployment patterns through a reduction in depot level maintenance and to test a maintenance policy similar to that employed by MSC to see what benefits there might be for the Navy.

Finally, Chapter VII addressed the question of whether phased maintenance is better than conventional maintenance. This was done in two steps: (1) as applied to the Atlantic Fleet AFSs and (2) as applied to other classes of ships. To evaluate the cost-effectiveness of the AFSPMP, a simple objective function was developed for the optimization problem in Chapter [illegible]. The objective function is linear and is based on deviations from preset goals. Based on several reasonable assumptions, it was determined that the AFSPMP is a cost-effective alternative to the conventional policy. This result was driven primarily by the supposition that four percent additional availability is worth the additional AFSPMP dollar costs. The expansion of the phased maintenance program to other ships was discussed as it applies to auxiliary and amphibious ships, frigates, destroyers, and cruisers. The limitations of the AFSPMP test were also addressed, as well as system management considerations and the physical and operational differences among classes of ships.

B. CONCLUSIONS

Several important conclusions were reached during the execution of this study.

First and foremost, it was concluded that there presently is no closed form solution to the problem of determining optimal maintenance policies for Navy ships. Therefore, in order to evaluate alternative maintenance policies the Navy must implement these policies and analyze the results. In effect, the Navy is attempting to find the optimal maintenance policy through an iterative process.

The next major conclusion was that the manday costs of maintaining a ship under phased maintenance are approximately ten percent less than under conventional maintenance, while the dollar costs have risen twenty percent. In addition, the costs of unplanned depot level maintenance experienced in the AFSPMP are one-half what they were prior to phased maintenance, indicating that the reliability of the AFSs may be improving. At the same time, the AFSPMP has resulted in a stabilization of deployment patterns and a four percent increase in overall availability.

It was also concluded that the Military Sealift Command (MSC) and Navy conventional maintenance costs are approximately the same. This implies that either the Navy has been able to reduce its costs relative to MSC, or MSC's costs have risen significantly. The former explanation seems unlikely.

The AFSPMP was evaluated against the objectives that were established for it at its inception and it was concluded that the AFSPMP has met those objectives. The availability problems appear to have been solved and many of the potential benefits of a progressive maintenance policy have been identified.

To answer the larger question of whether phased maintenance is better than conventional maintenance it was necessary to develop a simple model. A simple linear objective function for the optimization problem in Chapter IV was created to illustrate how the AFSPMP could be compared against the conventional policy. Based on several reasonable assumptions, the analysis indicated that the AFSPMP has been a better policy for the Atlantic Fleet AFSs than the conventional policy would have been.

Finally, it was concluded that due to the limitations of the AFSPMP test bed, the potential system management problems, and the differences in classes of ships, the expansion of the phased maintenance program should be conducted in a cautious manner and monitored very closely.

C. RECOMMENDATIONS

The first recommendation is that the Navy should conduct more research in an attempt to solve the Navy overhaul problem. Once a valid measure of effectiveness and set of functional relationships are discovered, the Navy may be able to substantially reduce its maintenance costs without reducing the operational readiness of its ships.

The Navy should also conduct a thorough comparison of the MSC and Navy maintenance costs. Indeed, if MSC can no longer maintain ships for less dollars than the Navy, then perhaps the Navy should not be implementing an MSC-type maintenance policy.

Although the AFSPMP appears to be a cost-effective alternative to conventional maintenance, the dollar costs of the program should be monitored very closely to determine exactly how much more phased maintenance costs. In addition, it is recommended that close observation of the phased maintenance program be continued as it is implemented for more classes of ships. The differences between other classes of ships and the AFSs may result in less than acceptable results. The more closely the costs and benefits are monitored, the sooner problems will be detected should they arise.

APPENDIX A

ESCALATION INDICES

The composite escalation factors below were obtained from two sources. The FY 74-80 factors were obtained from the Systems Analysis Division (Support for Manpower and Logistics) of the Navy Program Planning Office (OP-914). Those indices are the Office of the Secretary of Defense (OSD) Indices - Constant FY 84 Budget Dollars, dated 10 February 1983. The FY 81-88 indices were extracted from the Pricing and Cost Escalation Guidance for FY 85 Program Objective Memorandum (POM-85). Those indices were published in the Office of The Chief Of Naval Operations letter POM 85-9 Ser 902F/327492, dated 14 October 1982 (Chng 2 implemented).

TABLE A-1

Escalation Factors - Base Year FY 84 Dollars

FY	Factor	FY	Factor
74	.441	81	.88070
75	.486	82	.92535
76	.529	83	.96926
77	.574	84	1.00000
78	.624	85	1.03533
79	.698	86	1.07251
80	.804	87	1.11203

APPENDIX B

RAW DATA

This appendix contains seven tables of data and one letter that are used in Appendixes D and E for determining conversion factors and estimating costs. The purpose for providing the raw data is to enable the reader to trace the calculations from start to finish. The source of the data for each table is identified following each table.

TABLE B-1

Mandays and Dollars Expended for AFS Regular Overhauls

SHIP	YARD	DATES	NAVSEA MANDAYS	TYCOM MANDAYS	TOTAL MANDAYS	TOTAL K DOLS
USS CONCORD (AFS-5)	Norfolk Shipbuilding & Drydock Company	5/1/72 - 9/12/72	UNKNOWN	UNKNOWN	32,348	2,854
USS SAN DIEGO (AFS-6)	Norfolk Shipbuilding & Drydock Company	6/7/74 - 10/18/74	EST. 9,320*	EST. 35,944*	45,265	4,545
USS NIAGARA FALLS (AFS-3)	Todd Ship Beth Steel AAA Machine.	7/24/74 - 3/24/75	3,874	24,326	28,200	4,710
USS SAN JOSE (AFS-7)	Beth Steel	3/1/75 - 8/22/75	8,039	22,596	30,635	5,818
USS SYLVANIA (AFS-2)	Norfolk Naval Shipyard Horn Brothers Shipyard	5/15/75 - 12/3/75	UNKNOWN	UNKNOWN	36,534	5,699
USS MARS (AFS-1)	AAA Machine Service Engineer	2/9/77 - 11/3/77	10,336	46,739	57,075	10,724
USS CONCORD (AFS-5)	Private Yard (Est)	7/1/78 - 1/31/79	18,200	38,400	56,600	10,006
USS NIAGARA FALLS (AFS-3)	Beth. Steel Service Engineer	6/1/79 - 12/19/79	8,925	42,049	50,974	12,675
USS SAN JOSE (AFS-7)	SOS San Francisco	6/12/80 - 12/9/80	8,802	43,899	52,701	18,506

* Estimated NAVSEA and TYCON mandays based on known NAVSEA and TYCON costs and total mandays.

[Ref. 17: p. A-2]

TABLE B-2

Mandays Expended per Quarter on Interoverhaul Industrial Maintenance (RA/TA) - Prior to AFSPMP

QUARTER	USS SYLVANIA (AFS-2)			USS CONCORD (AFS-5)			USS SAN DIEGO (AFS-6)		
AFTER ROH	QTR/YR	$ COST	MANDAYS	QTR/YR	$ COST	MANDAYS	QTR/YR	$ COST	MANDAYS
1	1/76	69,763	528	1/79	115,984	663	4/74	ND	-
2	2/76	66,098	490	2/79	227,706	1265	1/75	ND	-
3	3/76	106,250	770	3/79	192,193	1045	2/75	ND	-
4	4/76	202,920	1439	4/79	16,376	87	3/75	ND	-
5	1/77	71,565	494	1/80	54,421	282	4/75	213,353	1667
6	2/77	241,136	1629	1/74	ND	-	1/76	61,836	468
7	3/77	159,917	1052	2/74	ND	-	2/76	99,143	734
8	4/77	0	0	3/74	ND	-	3/76	193,551	1403
9	1/78	39,860	251	4/74	ND	-	4/76	100,904	716
10	2/78	510,151	3130	1/75	ND	-	1/77	168,583	1163
11	3/78	131,569	788	2/75	ND	-	2/77	433,529	2929
12	4/78	90,002	526	3/75	18,825	151	3/77	35,523	234
13	1/79	15,461	88	4/75	321	3	4/77	121,431	778
14	2/79	142,718	793	1/76	154,240	1168	1/78	64,626	406
15	3/79	1,449,084	7875*	2/76	74,734	554	2/78	447,199	2928
16	4/79	321,299	1709	3/76	0	0	3/78	97,278	583
17	1/80	0	0	4/76	50,000	355	4/78	252,864	1479
18	2/80	139,590	705	1/77	283,241	1953	1/79	0	0
19	3/80	112,167	555	2/77	20,449	138	2/79	59,356	330
20				3/77	119,597	787	3/79	55,180	300

ND - No Data Available

* - Because of extensive repairs necessary prior to beginning PMP, this data point was treated as an anomaly and not used in development of Table A-5.

[Ref. 17: p. A-10]

TABLE B-3

Mandays Expended by SIMA and IMAs - Prior to AFSPMP

QUARTER	USS SYLVANIA (AFS-2)		USS CONCORD (AFS-5)		USS SAN DIEGO (AFS-6)	
AFTER ROH	QTR/YR	MANDAYS	QTR/YR	MANDAYS	QTR/YR	MANDAYS
1	1/76	470	1/79	571	4/74	209
2	2/76	298	2/79	619	1/75	342
3	3/76	404	3/79	452	2/75	164
4	4/76	395	4/79	219	3/75	635
5	1/77	374	1/80	165	4/75	234
6	2/77	853	1/74	No Data	1/76	264
7	3/77	153	2/74	No Data	2/76	829
8	4/77	475	3/74	No Data	3/76	714
9	1/78	528	4/74	438	4/76	210
10	2/78	367	1/75	144	1/77	247
11	3/78	481	2/75	223	2/77	291
12	4/78	708	3/75	177	3/77	951
13	1/79	370	4/75	375	4/77	225
14	2/79	468	1/76	399	1/78	322
15	3/79	340	2/76	480	2/78	1125
16	4/79	763	3/76	307	3/78	938
17	1/80	197	4/76	562	4/78	489
18	2/80	736	1/77	484	1/79	202
19	3/80	404	2/77	578	2/79	306
20	4/80	RSO I	3/77	774	3/79	364

[Ref. 17: p. A-16]

TABLE B-4

Mandays Expended on CIS - Prior to AFSPMP

QTR/YR	USS SYLVANIA (AFS-2) COST	MANDAYS	USS CONCORD (AFS-5) COST	MANDAYS	USS SAN DIEGO (AFS-6) COST	MANDAYS
4/78	-	-	6,500	38	38,797	227
1/79	-	-	19,905	114	22,206	127
2/79	20,900	116	2,199	12	26,265	146
3/79	890	5	-	-	348	2
4/79	43,090	229	-	-	RSO I	
1/80	13,132	68	75,423	391		
2/80	-	-	SRA II			
3/80	89,218	442				
4/80	RSO I					

[Ref. 17: p. A-17]

TABLE B-5

Mandays Expended on CIS - AFSPMP

QUARTER AFTER STARTING AFSPMP	USS SYLVANIA (AFS-2) QTR/YR	$ COST	MANDAYS	USS CONCORD (AFS-5) QTR/YR	$ COST	MANDAYS	USS SAN DIEGO (AFS-6) QTR/YR	$ COST	MANDAYS
1	1/81	184,052	868	3/80	80,858	400	1/80	20,449	106
2	2/81	-	-	4/80	48,729	235	2/80	41,574	210
3				1/81	-	-	3/80	-	-
4				2/81	41,303	190	4/80	-	-
5							1/81	75,439	356
6							2/81	38,636	178
7									
8									
9									
10									
11									
12									
13									
14									
15									
16									
17									
18									
19									
20									

[Ref. 17: p. A-21]

TABLE B-6

AFSPMP Actual and Projected Manday and Dollar Depot Level Maintenance Costs

	ACTUAL TO DATE					
	SRA & UNREP		RA/TA		TOTAL	
SHIP	MANDAYS	($000s)	MANDAYS	($000s)	MANDAYS	($000s)
USS SYLVANIA (AFS-2)	31,786	$12,233	2,272	$ 567	34,058	$12,800
USS CONCORD (AFS-5)	30,298	12,251	3,648	864	33,946	13,115
USS SAN DIEGO (AFS-6)	29,319	11,593	3,795	892	33,114	12,485
TOTAL	91,403	$36,077	9,715	$2,323	101,118	$38,400

	AS PROJECTED TO COMPLETE CYCLE					
	SRA & UNREP		RA/TA		TOTAL	
SHIP	MANDAYS	($000s)	MANDAYS	($000s)	MANDAYS	($000s)
USS SYLVANIA (AFS-2)	35,544	$14,030	5,057	$1,209	40,601	$15,239
USS CONCORD (AFS-5)	35,544	14,030	4,668	1,116	40,212	15,146
USS SAN DIEGO (AFS-6)	35,544	14,030	3,890	930	39,434	14,960
TOTAL	106,632	$42,090	13,615	$3,255	120,247	$45,345

	TOTAL COSTS					
	ACTUAL TO DATE		AS PROJECTED		TOTAL	
SHIP	MANDAYS	($000s)	MANDAYS	($000s)	MANDAYS	($000s)
USS SYLVANIA (AFS-2)	34,058	$12,800	40,601	$15,239	74,659	$28,039
USS CONCORD (AFS-5)	33,946	13,115	40,212	15,146	74,158	28,261
USS SAN DIEGO (AFS-6)	33,114	12,485	39,434	14,960	72,548	27,445
TOTAL	101,118	$38,400	120,247	$45,345	221,365	$83,745

[Ref. 18: pp. 8-9]

TABLE B-7

AFSPMP Actual and Projected Manday Intermediate Level Maintenance Costs

	ACTUAL MANDAYS			PROJECTED MANDAYS			
SHIP	SIMA/IMA	CIS	TOTAL	SIMA/IMA	CIS	TOTAL	TOTAL
USS SYLVANIA (AFS-2)	748	820	1,568	4,556	2,771	7,327	8,895
USS CONCORD (AFS-5)	1,186	438	1,624	4,288	2,608	6,896	8,520
USS SAN DIEGO (AFS-6)	1,557	866	2,423	3,752	2,182	5,934	8,357
TOTAL	3,491	2,124	5,615	12,596	7,561	20,157	25,772

[Ref. 16: p. III-10]

DEPARTMENT OF THE NAVY
COMMANDER MILITARY SEALIFT COMMAND
WASHINGTON D C 20390

REFER TO:
M-4EX
4700
Ser: 2046

MAY 17 1982

Information Spectrum, Inc.
1745 Jefferson Davis Highway
Arlington, Virginia 22202

Attention: Mr. Richard Osseck

Gentlemen:

The information requested during your meeting with Mr. Robert Jacobs on April 26, 1982 is forwarded for your consideration. Data covering the AFS-1 and AD-37 was developed primarily from studies performed in late 1976. The AE-26 data is based upon the same study, plus the cost and experience gained during the recently completed yard modification to civilian manning on the USNS KILAUEA (T-AE-26).

Because these data were generated primarily from the 1976 study and without the benefit of shipcheck, a caution must be noted. A high confidence level is placed upon the data if the assumed conditions were, in fact, the actual conditions existing on board the ships. It is emphasized that MSC has not visited the ships in question and has assumed a "typical" material condition and arrangement problems reflected by recent civilian manning of fleet ships experience.

Further, the 1976 study concluded that civilian manning of the AD-37 was impracticable due to crew size and limited space. The cost of making the space available also contributed to the impracticable assessment. (The validity of that evaluation is upheld by the current reassessment of the AD-37 CIVMOD.)

The data provided is considered of "study quality", however, if refined budget estimates are required, MSC will have to visit the ships and perform in-depth study of material conditions and solutions to CIVMOD problems.

Thomas W Allen

T. W. ALLEN
Engineering Officer

[Ref. 19: pp. J-1 to J-3]

AFS-1 Class

Assumptions

1. Material conditions good to excellent as found on the KILAUEA
2. Material upgrade of UNREP equipment costs are not part of the study, but costs to be incurred under either operational scenario.
3. The additional 3,000 sq. ft. of space in the deck house can be added without extraordinary measures.

Manning Scale Increase

Due to the size of the proposed crew quarters and support of an additional 10 people, an increased deck house must be provided. An estimated 3,000 sq. ft. (gross) addition to the deck house over and above the KILAUEA modifications.

One-Time Costs

\$4,500,000	-	Repair, overhaul, drydock, regulatory inspection and maintenance
\$19,750,000	-	Habitability modifications, support systems, and other changes required for civilian manning (includes estimated \$1,000,000 addition to support increase manning).

Recurring Costs

Fuel Consumption data is presented rather than costs so that the exact scenario may be calculated.

374	BBLS/Day	Underway
291	BBLS/Day	Underway Replenishing
90	BBLS/Day	In Port

Maintenance/Repair costs are budgeted on a yearly basis. Costs are normally presented as an overhaul/non-overhaul year which would be:

\$5,542,000 per year with an overhaul, or
\$4,675,000 per year without an overhaul.

The Following Average Costs Apply:

Overhaul	\$1,950,000
Mid-Period Repairs	1,200,000
Voyage Repairs	1,940,000
Alterations	830,000
Extraordinary Repairs	678,000
Accident/Damage	35,000

APPENDIX C

COST AGGREGATION MODEL

The purpose of this appendix is to describe the cost aggregation model that will be used in Appendix E to estimate total maintenance costs and construct confidence intervals, for every case where the data conforms to the requirements established below.

1. Cost Elements

The number of cost elements considered may vary according to the format of the available data. The primary elements that will be used are: Regular Overhaul (ROH) or Selected Restricted Availability (SRA), Restricted Availability / Technical Availability (RA/TA), Intermediate Maintenance Activity (IMA), and Commercial Industrial Service (CIS). In one case the IMA and CIS cost elements will be combined and in another a Drydocking SRA (DSRA) cost element will be required.

2. Data Requirements

The total cost for each cost element over a specified, but not necessarily equal, number of time periods is required for each Atlantic Fleet AFS. The analysis will be performed for both manday and dollar costs, where applicable.

3. Aggregation

a. Step One

The aggregation model will be exemplified using a random variable CE representing a generic cost element. The data for the CE random variable is conveniently arranged in Table C-1. It is reasonable to assume that the CE costs for each of the three ships are statistically independent. In addition, one can assume that the average CE costs per time period are independent realizations of the same random variable CE.

TABLE C-1

Example Cost Element Data Table

	AFS-2	AFS-5	AFS-6
TOTAL CE COST	C1	C2	C3
TIME PERIODS	N1	N2	N3
AVG CE COST/PERIOD	C1/N1	C2/N2	C3/N3

The CE sample mean U and standard deviation S can easily be calculated using the three average CE cost per time period values: U = (C1/N1 + C2/N2 + C3/N3)/3 and

S = ((C1/N1 - U)**2 + (C2/N2) - U)**2 + (C3/N3 - U)**2)/2.

b. Step Two

One could simply assume a particular sampling distribution for the random variable CE, but justifying that assumption would be difficult. Although the underlying distribution of random variable CE is unknown it is possible to approximate the distribution of the mean of CE.

The Central Limit Theorem can be employed to assert that the random variable CEa, defined to be the expected value (or mean) of the random variable CE, is approximately normally distributed, with mean Ua equal to U, and standard deviation Sa equal to S divided by the square root of three. That is,

Ua = U and Sa = S / SQR(3).

This assertion would be more tenable if the number of ships in the sample size was large, however, the approximation should be sufficient for the purposes of this study. The distribution of the average CE cost for one time period is now completely specified as N(CEa; Ua, Sa**2).

c. Step Three

The mean and standard deviation of the CEa random variable is in units of cost per time period, but the analysis requires the cost per cycle. The unit time period costs must be aggregated to reflect the entire cycle. This can be accomplished by defining a new random variable CEc = CEa1 + ... + CEap, where p is the number of time periods the CEa cost will be incurred. Random variable CEc is the sum of p independently and identically distributed random variables. Therefore, CEc is a normally distributed random variable with a mean Uc equal to p times Ua and standard deviation Sc equal to Sa times the square root of p. That is,

Uc = p * Ua and Sc = Sa * SQR(P).

The distribution of the total cycle cost for the generic cost element CE is now specified as N(CEc; Uc, Sc**2).

Assume there are k cost elements to be aggregated. Each of the steps above must be accomplished for each of those k cost elements. This will result in a set of k approximately normally distributed random variables:

N(CEc1; Uc1, Sc1**2),
N(CEc2; Uc2, Sc2**2),
.
.
.
and N(CEck; Uck, Sck**2).

e. Step Four

One may now define a random variable to represent the total cycle cost:

C = CEc1 + CEc2 + ... + CEck.

If the normality assumptions of steps one through three are correct, and if one assumes that the k random variables are independent, then random variable C will also be normally distributed. Random variable C will have a mean Ut that is the sum of the k means, and a standard deviation that is the square root of the sum of the k squared standard deviations. That is,

Ut = Uc1 + Uc2 + ... + Uck and

St = SQR(Sc1**2 + Sc2**2 + ... + Sck**2).

The distribution of the total cycle cost for a single AFS can now be specified as N(C; Ut, St**2).

f. Step Five

The final remaining task is to construct the desired confidence intervals. Based on the normality assumptions, a 100 times (1-alpha) percent confidence interval for the total cycle cost C is

Ut +/- Z(1-alpha/2) * St,

where Z(1-alpha/2) is the (1-alpha/2) quantile of the standard normal distribution. A 95 percent CI will be used in all cases so Z(1-alpha/2) becomes Z(.975) which equals 1.96.

4. Limitations

There are three possible problems with the analysis above but none should significantly alter the results of the analysis. The first of these concerns the application of the Central Limit Theorem in justifying normality, based a very small sample size. The second possible problem is the assumption in step four that each of the k cost elements are independent. The third area of concern is in the method of adding variances for aggregating the cost element uncertainties. This has been referred to as the fallacy of classical statistics with regard to cost estimating. Indeed, it is not intuitive that the percent uncertainty in the total cost should decrease as more cost elements are aggregated.

APPENDIX D

IMA AND CIS MANDAY TO DOLLAR COST CONVERSION MODELS

I. IMA CONVERSION MODEL

A. Objective

The objective of this model was to develop a means for converting Intermediate Maintenance Activity (IMA) manday cost data to dollar costs.

B. Methodology

The basic requirement was to determine the relationship between manday costs and total IMA dollar costs. The Visibility and Management of Operating and Support Costs - Ships (VAMOSC - Ships) was used as the source of data for this model. Fiscal year 77-82 IMA cost data, for the three Atlantic Fleet AFSs, was used to compute the desired conversion factors. The procedure was carried out in two steps: (1) The total IMA dollar cost in FY 84 dollars and the total manhour cost were computed for the eighteen ship-years of data and (2) The ratio of the IMA dollar cost to the manhour cost was computed and converted to units of mandays. This resulted in an index for converting manday costs to dollar costs (in FY 84 dollars).

1. Step One--Total Costs

The then year dollar costs were extracted directly from the Direct Intermediate Maintenance (2.0) cost element and converted to FY 84 dollars. All of the costs are summarized in Table D-1. Fiscal year 77-79 manday

TABLE D-1

FY 77-82
IMA Dollar and Manhour Costs for AFS-2, AFS-5, and AFS-6

AFS	FISCAL YR	DOLLAR COST (THEN YEAR)	DOLLAR COST (FY84 DOLLARS)	MANHOUR COST
	77	75477.0	131493.0	2945.0
	78	121370.0	194503.2	10976.0
2	79	117426.0	168232.1	12750.1
	80	165086.0	205330.8	12347.0
	81	60147.0	68294.5	6835.0
	82	61336.0	66284.1	5825.0
	77	137203.0	239029.6	5699.0
	78	177062.0	283753.2	12511.0
5	79	126169.0	180757.9	8949.0
	80	88189.0	109687.8	3349.0
	81	70761.0	80346.3	7457.0
	82	58498.0	63217.2	5515.0
	77	116512.0	202982.6	2500.0
	78	241204.0	386544.9	11147.4
6	79	93086.0	133361.0	5938.0
	80	213950.0	266107.0	8013.0
	81	51300.0	58249.1	4349.0
	82	32827.0	35475.2	2989.0
		TOTAL	2873649.5	130094.5

costs were calculated by dividing the Reported Maintenace Labor (2.1), by the Navy Composite Standard Rate (NCSR) contained in the report description. The VAMOSC - Ships system used the NCSR to compute the maintenance labor cost from manhour data. The cost element structure was changed in FY 80 so the FY 80-82 manday costs were computed by summing the Afloat Maintenance Manhours (2.1.1) and Ashore Maintenance Manhours (2.2.1). The total IMA costs for AFS-2, AFS-5, and AFS-6, from FY 77 through FY 82, were then calculated to be 130094.5 mandays and $2873649.5 (FY 84 dollars).

2. Step Two--Ratio

The ratio of the total IMA dollar cost in FY 84 dollars to the manhour cost is $22.1/manhour. The change of units from manhours to mandays is based on the assumption that there are eight manhours per manday. The revised ratio is therefore $176.8/manday ($FY 84 000s).

II. CIS MANDAY TO DOLLAR CONVERSION MODEL

A. Objective

The objective of this model was to develop a means for converting Commercial Industrial Service (CIS) manday cost data to dollars.

B. Methodology

The procedure below is based on the assumption of a variable dollar cost model, that is, the dollar costs are directly proportional to the manday costs. The procedure was to use appropriate data from the <u>AFS Phased Maintenance Program Preliminary Program Evaluation Report</u> [Ref. 17] to find the ratio of dollars to mandays, in constant FY 84 dollars. Table D-2 summarizes the data used to determine the conversion factor. The complete set of data is located in Table B-5.

The total dollar cost, in FY 81 dollars, was then converted to FY 84 dollars using the FY 81 escalation factor in Appendix A. This resulted in a total dollar cost of 339.3/.8807 = $385.3 (FY 84 000s). The conversion factor was then calculated to be 385.3*1000/1592 = $242.0 per manday.

TABLE D-2

FY 81 CIS Manday and Dollar Costs

	MANDAYS	FY 81 ($000s)
	868	184.0
	190	41.3
	356	75.4
	178	38.6
TOTAL	1592	339.3

APPENDIX E

COST ESTIMATE DETAILS

I. FY 75-79 CONVENTIONAL MAINTENANCE COST ESTIMATES

A. Objective

The objective of this section is to estimate the manday and dollar costs of maintaining an AFS under the conventional maintenance policy for a five year operating cycle commencing in FY 75 and ending in FY 79. The analysis considers only the depot and intermediate level costs. The results will be used as baseline costs in evaluating the phased maintenance program. All dollar estimates are in FY 84 dollars to aid in the comparison. Cost escalation was accomplished using the escalation factors in Appendix A.

B. Data Source

The estimates in this section are based primarily on the data contained in Appendix A to the <u>AFS Phased Maintenance Program Preliminary Program Evaluation Report</u> dated 30 September 1981 [Ref. 17]. The raw data is contained in Appendix B.

C. Methodology

Two different approaches were used to accomplish the objective. The first method involved summing the recorded cost data to determine the average maintenance costs for one AFS. The second method used the cost aggregation model that was outlined in Appendix C, resulting in point estimates and confidence intervals.

1. Method One

a. Description

The basic approach was to use available data to compute the average manday and dollar costs for each of the four cost elements. The averages were then summed to obtain the average maintenance cost for an Atlantic Fleet AFS. The four cost elements considered were Regular Overhaul (ROH), Restricted Availability / Technical Availability (RA/TA), Intermediate Maintenance (IMA), and Commercial Industrial Service (CIS).

The raw data from Tables B-1 through B-4 were placed in a multi-dimension matrix according to the ship, fiscal year, and cost element. The actual data portion of Table E-1 is the resulting matrix. Estimates were made for the cells for which no data was available. Some additional adjustments to the data were required to allow dollar costs to be escalated and because not all of the ships started their five year operating cycle at the same time. All of the adjustments to the raw data are documented following Table E-1.

b. Results

Once the adjustments were completed, the data for each ship was summed to form cost element subtotals for each fiscal year. The dollar costs were then

TABLE E-1

Atlantic Fleet AFS Dollar and Manday Costs
Actual and Adjusted FY 75-79 Data

USS Sylvania (AFS-2)

FISCAL YEAR	COST ELEMENT	ACTUAL DATA MANDAYS	ACTUAL DATA DOLLARS ($000s)	ADJUSTED DATA MANDAYS	ADJUSTED DATA DOLLARS ($000s)
75	ROH	0.0	0.0	0.0	3892.4
	RA/TA	N	N	1348.0	167.7
	IMA	N	N	883.6	75.9
	CIS	0.0	0.0	0.0	0.0
76	ROH	36534.0	5699.0	36534.0	1806.6
	RA/TA	1788.0	242.1	1788.0	242.1
	IMA	1172.0	M	1172.0	109.6
	CIS	0.0	0.0	0.0	0.0
77	ROH	0.0	0.0	0.0	0.0
	RA/TA	4614.0	675.5	4614.0	675.5
	IMA	1775.0	M	1775.0	180.1
	CIS	0.0	0.0	0.0	0.0
78	ROH	0.0	0.0	0.0	0.0
	RA/TA	4169.0	681.7	4169.0	681.7
	IMA	1851.0	M	1851.0	204.2
	CIS	0.0	0.0	0.0	0.0
79	ROH	0.0	0.0	0.0	0.0
	RA/TA	9282.0	1697.3	3375.8	610.5
	IMA	1886.0	M	1886.0	232.7
	CIS	121.0	21.8	121.0	21.8

USS Concord (AFS-5)

FISCAL YEAR	COST ELEMENT	ACTUAL DATA MANDAYS	ACTUAL DATA DOLLARS ($000s)	ADJUSTED DATA MANDAYS	ADJUSTED DATA DOLLARS ($000s)
75	ROH	0.0	0.0	0.0	0.0
	RA/TA	151.0P	18.8P	1725.0	210.6
	IMA	982.0	M	982.0	84.4
	CIS	0.0	0.0	0.0	0.0
76	ROH	0.0	0.0	0.0	0.0
	RA/TA	1725.0	229.2	1725.0	229.2
	IMA	1561.0	M	1561.0	146.0
	CIS	0.0	0.0	0.0	0.0
77	ROH	0.0	0.0	0.0	0.0
	RA/TA	3233.0	473.2	3233.0	473.2
	IMA	2398.0	M	2398.0	243.4
	CIS	0.0	0.0	0.0	0.0
78	ROH	0.0	0.0	0.0	4252.6
	RA/TA	0.0	0.0	0.0	0.0
	IMA	0.0	0.0	0.0	0.0

Table E-1 Contd.

	CIS	0.0	0.0	0.0	0.0
79	ROH	56600.0	10006.0	56600.0	5753.4
	RA/TA	2973.0	535.9	2973.0	535.9
	IMA	1642.0	M	1642.0	202.6
	CIS	164.0	28.6	164.0	28.6

USS San Diego (AFS-6)

FISCAL YEAR	COST ELEMENT	ACTUAL DATA MANDAYS	DOLLARS ($000s)	ADJUSTED DATA MANDAYS	DOLLARS ($000s)
75	ROH	45265.0	4545.0	45265.0	4946.2
	RA/TA	N	N	4062.7	496.1
	IMA	1350.0	M	1350.0	116.0
	CIS	0.0	0.0	0.0	0.0
76	ROH	0.0	0.0	0.0	0.0
	RA/TA	4272.0	567.9	4272.0	567.9
	IMA	2041.0	M	2041.0	190.9
	CIS	0.0	0.0	0.0	0.0
77	ROH	0.0	0.0	0.0	0.0
	RA/TA	5042.0	738.5	5042.0	738.5
	IMA	1699.0	M	1699.0	172.4
	CIS	0.0	0.0	0.0	0.0
78	ROH	0.0	0.0	0.0	0.0
	RA/TA	4695.0	730.5	4695.0	730.5
	IMA	2610.0	M	2610.0	287.9
	CIS	0.0	0.0	0.0	0.0
79	ROH	0.0	0.0	0.0	0.0
	RA/TA	2109.0	367.5	1444.7	251.7
	IMA	1361.0	M	932.3	115.0
	CIS	502.0	87.6	343.9	60.0

N= No data available
P= Partial lack of data (missing data for one or more quarters)
M= Only manday costs available (must be converted to dollars)

NOTES:

1. The actual data portion of the table reflects the ROH cost in the fiscal year that the ship came out of overhaul. The overhauls for AFS-2, AFS-5, and AFS-6 were completed 3 December 1975, 31 January 1979, and 18 October 1974, respectively. In each case the overhaul was accomplished during two fiscal years so it is reasonable to expect that not all of the mandays and dollars were expended during one fiscal year. The overhaul dollar cost for each of the bridged years is therefore assumed to be directly proportional to the fraction of time the ship was in overhaul, during that particular year. Sixty-eight point

Table E-1 Contd.

three percent of AFS-2's overhaul was during FY 75 therefore one can assume that .683*5699K = 3892.4K was expended in FY 75 and 5699K-3892.4K = 1806.6K in FY 76. Similar fractions were computed for AFS-5 resulting in an assumed expenditure of .425*10006K = 4252.6K in FY 78 and .575*10006K = 5753.4K in FY 79. The adjustment for AFS-6 was more complex because some of its overhaul was accomplished outside of the FY 75-79 time period of interest here. The easiest way to resolve the problem was to consider the start date of the overhaul as the start date of the AFS-6 five year cycle, and end the cycle the same number of months early. Eighty-six point five percent of the overhaul was during FY 74 so .865*4545K = 3931.4K was assumed to be expended during FY 74 and 4545K-3931.4K = 613.6K in FY 75. The FY 74 dollar cost was then escalated to FY 75 dollars so it could be included in the cost estimate. This resulted in an overhaul cost of 613.6K+3931.4K*(.486/.441) = 4946.2K in FY 75 dollars. The adjustments that were made to the end of cycle data are detailed in note 2.

2. Adjustments were necessary for FY 79 costs for AFS-6 because of the inclusion of FY 74 costs in the FY 75 ROH cost cell. The purpose of the adjustment was to balance out a five year cycle to avoid double counting. Since AFS-6 was in overhaul for 31.5% of FY 74, the FY 79 RA/TA, IMA, and CIS manday and dollar cost cells were reduced by 31.5%.

3. The FY 75 RA/TA cost for AFS-5 was estimated at 1725 mandays and 210.6K dollars. The manday estimate is the same as the figure for FY 76. The dollar estimate is the FY 76 RA/TA cost converted to FY 75 dollars using the OSD escalation indices. This results in (229.2K/.529)*.486 = 210.6K dollars.

4. The FY 75 RA/TA cost for AFS-2 was estimated as a percentage of the FY 76 cost using a cost per unit time approach. AFS-2 was not in overhaul for 62.2% of FY 75 and 82.5% of FY 76. The FY 75 manday cost was therefore estimated to be: 1788*(.622/.825) = 1348.0 mandays. The FY 76 RA/TA dollar cost must be converted to FY 75 dollars: (242.1K/.529)*.486 = 222.4K. The cost can now can be computed as before: 222.4K*(.622/.825) = 167.7K dollars. The same method was used to compute an estimate for the FY 75 IMA manday cost for AFS-2: 1172*(.622/.825) = 883.6 mandays.

5. The AFS-6 FY 75 RA/TA costs can be estimated using the same procedure. AFS-6 was out of overhaul for 95.1% of FY 75 and 100% of FY 76. The estimated FY 76 RA/TA manday cost

Table E-1 Contd.

is therefore 4272*(.951/1.0) = 4062.7 mandays. The FY 76 RA/TA dollar cost converted to FY 75 dollars is (567.9K/.529) * .486 = 521.7K dollars. The RA/TA cost for FY 75 is therefore estimated to be: 521.7*(.951/1.0) = 496.1K dollars.

6. The IMA dollar costs for all years were estimated using manday information. A $176.8/manday (in FY 84 dollars) conversion factor was derived in Appendix D. It was necessary to convert the $176.8/manday figure to dollars of the appropriate base year, using the escalation indices in Appendix A, prior to converting manday costs to dollars.

7. The FY 79 RA/TA costs for AFS-2 were reduced due to the comments in the data source. The data revealed that 1449.1K dollars and 7875 mandays were expended in quarter three of FY 79. The authors indicated that these costs were due to extensive repairs neccessary for entrance into the phased maintenance program. The authors also stated that it was considered an anomaly and therefore was excluded from their analysis [Ref. 17: p. A-10]. For this analysis, 25% of the manday and dollar costs, for that quarter, were used in making the adjustment to the data.

escalated to FY 84 dollars using the escalation factors listed in Appendix A of this study. The five sets of costs were then summed over the years to obtain the total manday and dollar cost, for each cost element. These final numbers represent the costs, broken down into the four cost elements, of maintaining the three ships for five years. The average cost for each of these elements was computed by dividing the total by three. The total cost of maintaining one ship for the five year cycle was then estimated by summing the four cost element averages. These data are shown in Table E-2.

TABLE E-2

FY 75-79 Conventional Maintenance Cost Estimates
(Average Cost per Ship)

COST ELEMENT	MANDAYS	DOLLARS (FY84 $000s)
ROH	46133.0	12219.8
RA/TA	14822.4	3772.5
IMA	7594.3	1342.6
CIS	209.6	52.7
TOTAL	68759.3	17387.6

2. Method Two

The cost aggregation model described in Appendix C was used to aggregate three cost elements: ROH, RA/TA, and IMA/CIS. The CIS cost for each quarter was added to the IMA cost due to limited CIS cost data.

a. Description

The number of adjustments made to the raw data are much fewer than in method one because the cost model does not require holes in the matrix to be filled. Each adjustment is noted in the applicable paragraph.

The calculation of an average ROH cost was based on the last three overhauls conducted on the Atlantic Fleet AFSs. The manday cost was straightforward to compute but the dollar costs required some adjustments so that the costs could be put into constant dollars. The adjusted data is in Table E-1 and note one of that table describes how the adjustments were made. The FY 84 dollar costs in

Table E-3 were computed by summing the escalated then year dollar ROH costs in Table E-1.

TABLE E-3

FY 81-85 Conventional Maintenance ROH Cost Data (Cost/Cycle)

SHIP	ROH START	ROH END	MANDAYS	(FY 84 $000s)
AFS-2	5/15/75	12/03/75	36534.0	11424.2
AFS-5	7/01/78	01/31/79	56600.0	15057.8
AFS-6	6/07/74	10/18/74	45265.0	10177.4

The computation of the average RA/TA cost was based on the unadjusted RA/TA quarterly data in Table B-2. Forty-eight of the forty-nine available ship-quarters of data were utilized. The remaining quarter was excluded from consideration due to the reason cited in note seven of Table E-1. The manday and dollar RA/TA costs are shown in Table E-4.

The computation of the average IMA/CIS cost was based on the unadjusted IMA data in Table B-3 and CIS data in Table B-4. The manday costs were converted directly to FY 84 dollars by multiplying the number of mandays in the first part of the table by the conversion factor $176.8/manday. This factor was derived in Appendix D. The FY 79 and 80 CIS costs are also included in Table E-5, on the line following the corresponding IMA cost.

TABLE E-4

FY 81-85 Conventional Maintenance RA/TA Cost Data
(Cost/Quarter)

MANDAYS

FY	AFS-2 MANDAYS	Q	AFS-5 MANDAYS	Q	AFS-6 MANDAYS	Q
75		0	151.0	1		0
76	1788.0	3	1725.0	4	4272.0	4
77	4614.0	4	3233.0	4	5042.0	4
78	4169.0	4		0	4695.0	4
79	1407.0	3	2973.0	3	2109.0	4
80	2969.0	4	369.0	2		0
TOTAL	14947.0	18	8451.0	14	16118.0	16
COST/QTR	830.4		603.6		1007.4	

DOLLARS

FY	AFS-2 CURRENT	AFS-2 FY84	Q	AFS-5 CURRENT	AFS-5 FY84	Q	AFS-6 CURRENT	AFS-6 FY84	Q
75			0	18.8	38.7	1			0
76	242.1	457.6	3	229.2	433.3	4	567.9	1073.5	4
77	675.5	1176.8	4	473.2	824.4	4	738.5	1286.6	4
78	681.7	1092.5	4			0	730.5	1170.7	4
79	248.2	355.6	3	535.9	767.8	3	367.5	526.5	4
80	573.1	712.8	4	70.8	88.0	2			0
TOTAL		3795.3	18		2152.2	14		4057.3	16
COST/QTR		210.8			153.7			253.6	

TABLE E-5

FY 81-85 Conventional Maintenance IMA/CIS Cost Data
(Cost/Quarter)

MANDAYS

FY		AFS-2 MANDAYS	Q	AFS-5 MANDAYS	Q	AFS-6 MANDAYS	Q
75			0	982.0	4	1350.0	4
76		1172.0	3	1561.0	4	2041.0	4
77		1775.0	4	2398.0	4	1699.0	4
78		1851.0	4		0	2610.0	4
79		1886.0	4	1642.0	3	1361.0	4
	CIS	121.0		164.0		502.0	
80		2100.0	4	384.0	2		0
	CIS	739.0		391.0			
TOTAL		9644.0	19	7522.0	17	9563.0	20
COST/QTR		507.6		442.5		478.2	

DOLLARS ($000s)

FY		AFS-2 FY84	Q	AFS-5 FY84	Q	AFS-6 FY 84	Q
75			0	173.6	4	238.7	4
76		207.2	3	276.0	4	360.8	4
77		313.8	4	424.0	4	300.4	4
78		327.2	4		0	461.4	4
79		333.4	4	290.3	3	240.6	4
	CIS	31.2		41.0		125.5	
80		371.3	4	67.9	2		0
	CIS	180.8		93.8			
TOTAL		1764.9	19	1366.6	17	1727.4	20
COST/QTR		92.9		80.4		86.4	

b. Aggregation

(1) Step One. The ROH, RA/TA, and IMA/CIS manday and dollar cost data is summarized in Tables E-6 and E-7. The sample means and standard deviations are also included.

TABLE E-6

FY 75-79 Conventional Maintenance ROH, RA/TA, and IMA/CIS Manday Cost Data

	AFS-2 MANDAYS	AFS-5 MANDAYS	AFS-6 MANDAYS
TOTAL ROH	36534.0	56600.0	45265.0
NUMBER ROHs	1	1	1
AVG ROH/CYCLE	36534.0	56600.0	45265.0
AVERAGE AVG ROH COST / CYCLE = 46133.0 mandays			
STANDARD DEVIATION = 10061.1 mandays			
TOTAL RA/TA	14947.0	8451.0	16118.0
NUMBER QTRS	18	14	16
AVG RA/TA	830.4	603.6	1007.4
AVERAGE AVG RA/TA COST / QUARTER = 813.8 mandays			
STANDARD DEVIATION = 202.4 mandays			
TOTAL IMA/CIS	9644.0	7522.0	9563.0
NUMBER QTRS	19	17	20
AVG IMA/CIS	507.6	442.5	478.2
AVERAGE AVG IMA/CIS COST / QUARTER = 476.1 mandays			
STANDARD DEVIATION = 32.6 mandays			

1. The ROH costs were extracted from Table E-3.
2. The RA/TA costs were extracted from Table E-4.
3. The IMA/CIS costs were extracted from Table E-5.

TABLE E-7

FY 75-79 Conventional Maintenance ROH, RA/TA, and IMA/CIS Dollar Cost Data

	AFS-2 DOLLARS	AFS-5 DOLLARS	AFS-6 DOLLARS
TOTAL ROH	11424.2	15057.8	10177.4
NUMBER ROHs	1	1	1
AVG ROH/CYCLE	11424.2	15057.8	10177.4
AVERAGE AVG ROH COST / CYCLE = $12219.8			
STANDARD DEVIATION = $2535.6			
TOTAL RA/TA	3795.3	2152.2	4057.3
NUMBER QTRS	18	14	16
AVG RA/TA	210.8	153.7	253.6
AVERAGE AVG RA/TA COST / QUARTER = $206.0			
STANDARD DEVIATION = $50.1			
TOTAL IMA/CIS	1764.9	1366.6	1727.4
NUMBER QTRS	19	17	20
AVG IMA/CIS	92.9	80.4	86.4
AVERAGE AVG IMA/CIS COST / QUARTER = $86.6			
STANDARD DEVIATION = $6.2			

1. All dollars are in thousands of FY 84 dollars.
2. The ROH costs were extracted from Table E-3.
3. The RA/TA costs were extracted from Table E-4.
4. The IMA/CIS costs were extracted from Table E-5.

(2) Step Two. The Central Limit Theorem can be used to assert that the distributions of random variables ROHa, RATAa, and IMACISa are normally distributed with the mean and variance parameters indicated in Table E-8.

(3) Step Three. The ROHa cost already pertains to a cycle but the other two quarterly elements must be aggregated into cycle costs. The ROHa cost is

TABLE E-8

FY 75-79 Conventional Maintenance ROH, RA/TA, and IMA/CIS Time Period Cost Distributions

MANDAYS	DOLLARS
N(ROHa ;46133.0,5808.8**2)	N(ROHa ;12219.8,1463.9**2)
N(RATAa ; 813.8, 116.8**2)	N(RATAa ; 206.0, 28.9**2)
N(IMACISa; 476.1, 18.8**2)	N(IMACISa; 86.6, 3.6**2)

1. ROHa costs are per cycle.
2. RATAa and IMACISa are per quarter.

simply redefined to be ROHc. There are eighteen quarters of RA/TA, IMA, and CIS costs to aggregate to the cycle level. The eighteen quarters result from the observation that the three AFS overhauls lasted an average of six months. If one assumes that no RA/TA, IMA, or CIS costs are incurred during an overhaul, then eighteen quarters of costs remain to be aggregated. The sums of normally distributed random variables are normally distributed random variables. Therefore, the means and variances of the new random variables RATAc and IMACISc, representing the cycle costs, are the old means and variances multiplied by eighteen. The new distributions are displayed in Table E-9.

TABLE E-9

FY 81-85 Conventional Maintenance ROH, RA/TA, and IMA/CIS Cycle Cost Distributions

MANDAYS	DOLLARS
N(ROHc ;46133.0,5808.8**2)	N(ROHa ;12219.8,1463.9**2)
N(RATAc ;14648.4, 495.5**2)	N(RATAc ; 3708.0, 122.6**2)
N(IMACISc; 8569.8, 79.8**2)	N(IMACISc; 1558.8, 15.3**2)

(4) Step Four. The total cycle cost can now be defined to be: C = ROHc + RATAc + IMACISc. It is normally distributed with a mean and variance equal to the sum of the component means and variances, respectively. The total cycle cost is, therefore, N(C;69351.2,5830.4**2) in mandays and N(C;17486.6;1469.0**2) in dollars (FY 84 000s).

(5) Step Five. Ninety-five percent confidence intervals can now be constructed for the total cycle manday and dollar costs:

69351.2 +/- 5830.4*1.96 or (57923.6,80778.8) mandays and 17486.6 +/- 1469.0*1.96 or (14607.4,20365.8) dollars (FY 84 000s).

II. FY 81-85 CONVENTIONAL MAINTENANCE COST PROJECTIONS

A. Objective

The objective of this section is to estimate the manday and dollar costs of maintaining an AFS under the conventional maintenance policy for a five year operating cycle commencing in FY 81 and ending in FY 85. The analysis considers only depot and intermediate level maintenance and is an attempt to estimate the costs of conventional maintenance as if the phased maintenance program had not been implemented.

B. Data Source

The source of data for these estimates is Appendix A to the <u>AFS Phased Maintenance Program Preliminary Program</u>

Evaluation Report, dated 30 September 1981 [Ref. 17]. Some of this data is enclosed in Appendix B of this study.

C. Methodology

Two basic cost estimates are presented in this section. The first one is the estimate, in mandays only, that was contained in the AFS phased maintenance report. The second method makes use of regression analysis to estimate ROH cost growth and then uses the cost aggregation model described in Appendix C.

1. Method One

This cost estimate comes directly from the AFS Phased Maintenance Program Preliminary Program Evaluation Report dated September 1981. The Deputy Chief of Naval Operations (Logistics) Ships Maintenance and Modernization Division (OP-43) and NAVSEA are primarily interested in manday costs; therefore, no dollar cost estimates were included in the report. Table E-10 summarizes the contents of Table A-15 and A-16 of that report. The cost element totals in those tables were divided by three to estimate the cost per ship. The ROH costs in that report were projected using exponential regression.

2. Method Two

The cost aggregation model outlined in Appendix C was used to determine this set of point estimates and confidence intervals. The basic assumption for this method is that the cost to maintain a ship increases as the ship

TABLE E-10

Phased Maintenance Program Evaluation Report
FY 81-85 Conventional Maintenance Projection
(Cost Per Ship)

COST ELEMENT	MANDAYS
ROH	71447.3
RA/TA	15833.3
IMA	7997.3
CIS	1926.0
TOTAL	97203.9

gets older. The focus will be on ROH costs because graphs of those costs against time show a definite increasing trend. Linear and exponential regression models were formulated and evaluated.

The RA/TA, IMA, and CIS cost elements are assumed to be the same as the FY 75-79 conventional policy estimates because no trends were apparent in the limited data. These costs were summarized in Tables E-6 and E-7.

a. ROH Cost

Two sets of data were considered for the regression analysis: the Atlantic Fleet AFSs by themselves, and all of the AFSs grouped together. The latter alternative provides more data points for conducting the regression analysis. The drawback is that there may be differences between the Atlantic and Pacific fleets that would confound the results of the regression, especially for dollar costs. It is well known that dollar costs vary significantly between public and private shipyards, from shipyard to shipyard, and particularly from coast to coast. For this reason, the entire data set was utilized only in the manday cost models. The data used in the regression analysis is presented in Table E-11. It is based on the ROH data presented in Appendix B to this study. The constant dollar costs for the three Atlantic Fleet AFS overhauls, for which escalation indices were available, were computed in the previous section and presented in Table E-3. The calendar dates for each overhaul were converted to the fiscal year by determining which fiscal year contained the midpoint of the overhaul.

TABLE E-11

ROH Cost Data

FY	FLEET	MANDAYS	CURRENT $K	FY84 $K
72	LANT	32348	2854	
74	LANT	45265	4545	10177.4
75	LANT	36534	5699	11424.2
79	LANT	56600	10006	15057.8
75	PAC	28200	4710	
75	PAC	30635	5818	
77	PAC	57075	10724	
79	PAC	50974	12675	
80	PAC	52701	18506	

One-sided hypothesis tests were conducted with the probability of a type one error equal to .10. The hypothesis was Ho: b = 0 vs. H1: b > 0, where b is the slope in the regression equation. A "significant" in tables E-12 or E-13 implies that Ho was rejected which means that the regression equation is significant.

The results of the linear and exponential regression analysis on the data in Table E-11 are presented in Tables E-12 and E-13, respectively.

TABLE E-12

ROH Linear Regression Results

Atlantic Fleet Data:

MANDAYS = -199883.4 + 3234.3 * FY
SE = 6041.5 R2 = .788
CV = .142 tb = 2.73 => significant

DOLLARS = -60492.6 + 956.7 * FY
SE = 208.9 R2 = .997
CV = .017 tb = 17.14 => significant
(dollars in FY84 000s)

Atlantic and Pacific Fleet Data:

MANDAYS = -206357.0 + 3276.3 * FY
SE = 8053.8 R2 = .576
CV = .186 tb = 3.09 => significant

TABLE E-13

ROH Exponential Regression Results

Atlantic Fleet Data:

ln(MANDAYS) = 5.152 + .073 * FY
SE = .146 R2 = .764
CV = .014 tb = 2.54 => significant

ln(DOLLARS) = 3.645 + .076 * FY
SE = .029 R2 = .990
CV = .003 tb = 9.86 => significant
(dollars in FY 84 000s)

Atlantic and Pacific Fleet Data:

ln(MANDAYS) = 4.762 + .077 * FY
SE = .200 R2 = .550
CV = .019 tb = 2.92 => significant

The linear models, for Atlantic Fleet data only, resulted in larger R-squared values than any of the exponential models, or linear models based on all of the data. In addition, there was no a-priori reason to believe that the data should be exponential. For these reasons, the linear models based only on the Atlantic Fleet data were used to project the ROH manday and dollar costs. This is in contrast to the exponential regression used by American Management Systems, Inc. in the method one cost projection. If the AFSs had not entered the phased maintenance program it was expected that they would undergo regular overhauls during the fiscal years indicated in Table E-14 [Ref. 17: pp. A-2, A-31]. The projected manday and dollar costs are presented in Table E-14.

TABLE E-14

Projected FY 81-85 Conventional Maintenance Policy
Average ROH Manday and Dollar Costs

	AFS-2	AFS-5	AFS-6
FISCAL YR	FY 81	84	85
MANDAYS	62094.9	71797.8	75032.1
FY 84 ($000s)	17000.1	19870.2	20826.9

b. Aggregation

(1) Step One. A summary of the ROH manday and dollar cost data along with the sample means and standard deviations is presented in Table E-15. The same information for the RA/TA, IMA, and CIS costs was previously presented in Tables E-6 and E-7.

TABLE E-15

FY 81-85 Projected Conventional Maintenance
Manday and Dollar Cost Data

	AFS-2	AFS-5	AFS-6
TOTAL ROH MANDAYS	62094.9	71797.8	75032.1
NUMBER ROHs	1	1	1
AVG ROH/CYC1E	62094.9	71797.8	75032.1

AVERAGE AVG ROH COST/CYCLE = 69641.6
STANDARD DEVIATION = 6732.7

TOTAL ROH DOLLARS	17000.1	19870.2	20826.9
NUMBER ROHs	1	1	1
AVG ROH/CYCLE	17000.1	19870.2	20826.9

AVERAGE AVG ROH COST/CYCLE = $19232.4 (FY 84 000s)
STANDARD DEVIATION = $1991.5 (FY 84 000s)

(2) Steps Two and Three. The second and third steps in aggregating the RA/TA, IMA, and CIS costs were completed in the previous section of this appendix. The results are displayed in Table E-9. Using the information in Table E-15, the revised ROHc random variable is: N(ROHc; 69641.6, 3887.1**2) in mandays and N(ROHc; 19232.4, 1149.8**2) in dollars.

(3) Step Four. The total cycle cost can now be defined to be C = ROHc + RATAc + IMACISc. It is normally distributed with a mean and variance equal to the sum of the means and a sum of the variances, respectively. The total cycle cost C is, therefore, N(C;92859.8, 3919.4**2) in mandays and N(C;24499.2,1156.4**2) in dollars (FY 84 000s).

(4) Step Five. Ninety-five percent confidence intervals can now be constructed for the total cycle manday and dollar costs:

92859.8 +/- 3919.4*1.96 or (85177.8,100541.8) mandays and 24499.2 +/- 1156.4*1.96 or (22232.6,26765.7) dollars (FY 84 000s).

III. FY 81-85 PHASED MAINTENANCE COST PROJECTIONS

A. Objective

The objective of this section is to estimate the manday and dollar costs of maintaining an AFS under the phased maintenance policy for a five year operating cycle commencing in FY 81 and ending in FY 85. The analysis considers only the depot and intermediate level maintenance.

B. Data Source

The sources of data for these estimates are the second and third formal AFS Phased Maintenance Program (AFSPMP) evaluation reports [Ref. 16 and 18] which were produced by the Naval Sea Systems Command (NAVSEA 911) in conjunction with American Management Systems, Inc. The reports are dated March 1983 and August 1983, respectively. The raw data from those studies is contained in Appendix B of this study.

C. Methodology

Two methods were used to estimate the desired costs. The first one is a simple aggregation of the costs listed in the two AFSPMP evaluation reports and results in point estimates only. The second method makes use of the cost aggregation model described in Appendix C to determine point estimates and confidence intervals for the dollar and manday costs.

1. Method One

The depot and intermediate level manday and dollar cost data are summarized in Table E-16. The depot level manday and dollar cost data were extracted from Table B-6. The intermediate level manday data was extracted from

TABLE E-16

AFS Phased Maintenance Program Evaluation Reports
FY 81-85 AFSPMP Maintenance Policy Projected Depot and Intermediate Level Manday and Dollar Costs

	AFS-2	AFS-5	AFS-6
DEPOT MANDAY	74659.0	74158.0	72548.0
DEPOT DOLLAR	28039.0	28261.0	27445.0
IMA MANDAY	5304.0	5474.0	5309.0
IMA DOLLAR	937.7	967.8	938.6
CIS MANDAY	3591.0	3046.0	3048.0
CIS DOLLAR	869.0	737.1	737.6
TOTAL MANDAY	83554.0	82678.0	80905.0
TOTAL DOLLAR	29845.7	29965.9	29121.2

1. All dollars in thousands.
2. The IMA and CIS dollar costs were computed using the mandays in Table B-7 and the conversion factors in Appendix D.

Table B-7. The intermediate level dollar costs had to be estimated from the manday costs in Table B-7 using the conversion factors derived in Appendix D. The IMA manday to dollar conversion factor is $176.8 ($FY 84) per manday and the CIS manday to dollar conversion factor is $242.0 ($FY 84) per manday.

A point estimate of the total FY 81-85 AFSPMP depot and intermediate level maintenance costs for the average AFS is then calculated to be 82379.0 mandays and $29644.3 (000s). These averages were determined by computing the total manday and dollar costs for the three ships and dividing by three. The total dollar cost is not given in terms of a base year because the depot level costs in the program evaluation report were the sum of various then year dollars.

2. Method Two

The cost aggregation model in Appendix C was used to determine point estimates and confidence intervals for the dollar and manday costs.

a. Step One

The SRA, RA/TA, IMA, and CIS manday and dollar cost data is contained in Tables E-17 and E-18. These data were extracted from Tables B-6 and B-7. The sample means and standard deviations are also displayed.

TABLE E-17

FY 81-85 AFSPMP SRA, RA/TA, IMA, and CIS Manday Cost Data

	AFS-2 MANDAYS	AFS-5 MANDAYS	AFS-6 MANDAYS
TOTAL SRA	31786.0	30298.0	29319.0
NUMBER SRAs	2	2	2
AVG SRA/CYCLE	15893.0	15149.0	14659.5

AVERAGE AVG SRA COST / CYCLE = 15233.8 mandays
STANDARD DEVIATION = 621.1 mandays

	AFS-2 MANDAYS	AFS-5 MANDAYS	AFS-6 MANDAYS
TOTAL RA/TA	2272.0	3648.0	3795.0
NUMBER QTRS	7	8	10
AVG RA/TA	324.6	456.0	379.5

AVERAGE AVG RA/TA COST / QUARTER = 386.7 mandays
STANDARD DEVIATION = 66.0 mandays

	AFS-2 MANDAYS	AFS-5 MANDAYS	AFS-6 MANDAYS
TOTAL IMA	748.0	1186.0	1557.0
NUMBER QTRS	3	4	6
AVG IMA	249.3	296.5	259.5

AVERAGE AVG IMA COST / QUARTER = 268.4 mandays
STANDARD DEVIATION = 24.8 mandays

	AFS-2 MANDAYS	AFS-5 MANDAYS	AFS-6 MANDAYS
TOTAL CIS	820.0	438.0	866.0
NUMBER QTRS	3	4	6
AVG CIS	273.3	109.5	144.3

AVERAGE AVG CIS COST / QUARTER = 175.7 mandays
STANDARD DEVIATION = 86.3 mandays

TABLE E-18

FY 81-85 AFSPMP SRA, RA/TA, IMA, and CIS Dollar Cost Data

	AFS-2 DOLLARS	AFS-5 DOLLARS	AFS-6 DOLLARS
TOTAL SRA	12233.0	12251.0	11593.0
NUMBER SRAs	2	2	2
AVG SRA/CYCLE	6116.5	6125.5	5796.5

AVERAGE AVG SRA COST / CYCLE = $6012.8
STANDARD DEVIATION = $187.4

	AFS-2 DOLLARS	AFS-5 DOLLARS	AFS-6 DOLLARS
TOTAL RA/TA	567.0	864.0	892.0
NUMBER QTRS	7	8	10
AVG RA/TA	81.0	108.0	89.2

AVERAGE AVG RA/TA COST / QUARTER = $92.7
STANDARD DEVIATION = $13.8

	AFS-2 DOLLARS	AFS-5 DOLLARS	AFS-6 DOLLARS
TOTAL IMA	132.2	209.7	275.3
NUMBER QTRS	3	4	6
AVG IMA	44.1	52.4	45.9

AVERAGE AVG IMA COST / QUARTER = $47.5
STANDARD DEVIATION = $4.4

	AFS-2 DOLLARS	AFS-5 DOLLARS	AFS-6 DOLLARS
TOTAL CIS	198.4	106.0	209.6
NUMBER QTRS	3	4	6
AVG CIS	66.1	26.5	34.9

AVERAGE AVG CIS COST / QUARTER = $42.5
STANDARD DEVIATION = $20.9

1. All dollars in thousands.
2. The IMA and CIS costs were computed using the mandays in Table E-17 and the conversion factors in Appendix D.

b. Step Two

The Central Limit Theorem can be used to assert that the distributions of random variables SRAa, RATAa, IMAa, and CISa are normally distributed as indicated in Table E-19. In addition, there is a Drydocking SRA (DSRA) once each cycle that is estimated to be 1.36 times as long as a normal SRA [Ref. 16: p. III-8].

TABLE E-19

FY 81-85 AFSPMP Average SRA, RA/TA, IMA, and CIS Cost Distributions

MANDAYS	DOLLARS
N(SRAa ;15233.8,358.6**2)	N(SRAa ;6012.8,108.2**2)
N(RATAa; 386.7, 38.1**2)	N(RATAa; 92.7, 8.0**2)
N(IMAa ; 268.4, 14.3**2)	N(IMAa ; 47.5, 2.5**2)
N(CISa ; 175.7, 49.8**2)	N(CISa ; 42.5, 12.1**2)

1. SRAa costs are per SRA.
2. RA/TA, IMA, and CIS costs are per quarter.

The DSRAa random variable is a simple linear transformation of the SRAa random variable. This implies that DSRAa is normally distributed with a mean that is 1.36 times the mean of SRAa and a variance that is 1.36 squared times the variance of SRAa: N(DSRAa; 20718.0,487.7**2) for the manday case and N(DSRAa; 8177.4,147.2**2) for the dollar case.

c. Step Three

The five cost elements must now be aggregated into five sets of cycle costs. The only cost variable that does not require change is DSRAa. Since it is already in units of cost per cycle it will simply be redefined to be DSRAc. There are, however, three other SRAs and twenty quarters of RA/TA, IMA, and CIS costs that must be aggregated to the cycle level. The sums of normally distributed random variables are normally distributed random variables. Therefore, the means and variances of the new random variables SRAc, RATAc, IMAc, and CISc, representing the cycle costs, are the old means and variances multiplied by the number of time periods in a cycle--three for SRA and twenty for RA/TA, IMA, and CIS. The new distributions are displayed in Table E-20.

TABLE E-20

FY 81-85 AFSPMP SRA, DSRA, RA/TA, IMA, and CIS Cycle Cost Distributions

MANDAYS	DOLLARS
N(SRAc ;45701.4,621.1**2)	N(SRAc ;18038.4,187.4**2)
N(DSRAc;20718.0,487.7**2)	N(DSRAc; 8177.4,147.2**2)
N(RATAc; 7734.0,170.4**2)	N(RATAc; 1854.0, 35.8**2)
N(IMAc ; 5368.0, 64.0**2)	N(IMAc ; 950.0, 11.2**2)
N(CISc ; 3514.0,222.7**2)	N(CISc ; 850.0, 54.1**2)

d. Step Four

The total cycle cost can now be defined to be: C = SRAc + DSRAc + RATAc + IMAc + CISc. It is normally distributed with a mean equal to the sum of the means, and a variance equal to the sum of the variances. The total cycle cost is, therefore, N(C;83035.4,840.4**2) in mandays and N(C;29869.8;247.2**2) in dollars.

e. Step Five

Ninety-five percent confidence intervals can now be constructed for the total cycle manday and dollar costs:

83035.4 +/- 840.4*1.96 or (81388.2,84682.6) mandays and 29869.8 +/- 247.2*1.96 or (29385.3,30354.3) dollars. The dollars are in thousands but no base year is given due to the fact that then year dollars were added together in the original data.

IV. FY 81-85 MILITARY SEALIFT COMMAND COST ESTIMATE

A. Objective

The objective of this section is to estimate the depot and intermediate level maintenance manday and dollar costs for an AFS under the Military Sealift Command maintenance policy for a five year operating cycle commencing in FY 81 and ending in FY 85. This is an attempt to determine how much it would cost MSC to maintain an AFS, if one was transferred to it. The dollar estimates were converted to FY 84 dollars using the escalation factor in Appendix A to aid in comparing different maintenance policies. None of the one-time conversion costs (from Navy to civil service manning) were considered. In addition, no attempt was made to incorporate the difference in crewing costs.

B. Data Source

The estimate in this section is based primarily on the information contained in a letter from the Military Sealift Command (MSC) to Information Spectrum, Inc. This letter was the basis for the MSC maintenance cost calculations in Final Report, Civilian Manning of AE, AFS, and AD Type Support Ships [Ref. 19], which was published 5 April 1983. The letter was incorporated as Appendix J to that study and is reproduced in Appendix B to this study. The Military Sealift Command stated, "A high confidence level is placed upon the data if the assumed conditions were, in fact, the actual conditions existing on board the ships." [Ref. 19: p. J-2] Their primary assumption was that the material condition of the ship would be good to excellent. The reported average maintenance and repair cost data is reproduced in Table E-21. The overhaul and mid-period repair averages are biennial costs and the remaining four are annual costs.[1]

TABLE E-21

MSC Estimated Average Maintenance and Repair Costs

COST ELEMENT	FY 82 ($000s)
OVERHAUL	1950.0
MID-PERIOD REPAIR	1200.0
VOYAGE REPAIRS	1940.0
ALTERATIONS	830.0
EXTRAORDINARY REPAIRS	678.0
ACCIDENT/DAMAGE	35.0

[1]Telephone conversation with Mr. Richard Osseck of Information Spectrum Inc., on 26 January 1984.

C. Methodology

The cost element structure was not conducive to estimating intermediate level costs but the MSC equivalent of intermediate maintenance is probably included in the cost elements above. The first four cost elements in Table E-21 were aggregated to form estimates of the scheduled and unscheduled depot level maintenance costs. These costs were then summed to estimate the total cycle maintenance cost. The last two average costs were not included because it was not clear what those costs represent.

The overhaul, mid-period repair, and alteration cost elements were considered to be scheduled depot level work. These elements represent an annual cost of 1950.0/2 + 1200/2 + 830.0 = $2405.0 (FY 82 000s) or 2405.0/.92535 = $2599.0 (FY 84 000s). The unscheduled depot level annual cost was $1940.0 (FY 82 000s) or 1940.0/.92535 = $2096.5 (FY 84 000s). The estimated cycle costs for these elements are five times as large: $12995.0 and $10482.5 (FY 84 000s). The total annual cost of depot level maintenance is 2599.0 + 2096.5 = $4695.5 (FY 84 000s). The depot level cost for a five year operating cycle can then be calculated to be $23477.5 (FY 84 000s) by summing the two cycle costs or multiplying the total annual cost by five.

The data was too limited to construct a standard confidence interval because MSC did not include an estimate of the variance. A confidence interval can be generated if one assumes a distribution and variance for the annual cost. It was assumed that the annual cost is a normally distributed random variable (Ca) with mean Ua = $4695.5. The variance was estimated by assuming that the maximum and minimum possible Ca values were within +/- P*100 percent of Ua. The standard deviation was then estimated to be (2*P*Ua/6). The distribution of the annual cost was then specified to be N(Ca; 4695.5,(2*P*Ua/6)**2). The cycle cost was assumed to be a normally distributed random variable because it is the sum of five independent normally distributed random variables. The cycle mean and variance are five times the annual mean and variance resulting in a cycle cost with distribution N(Cc;23477.5, 5*((2*P*Ua/6) **2)). Confidence intervals were then established using Step 5 of Appendix C. Table E-22 presents the lower and upper 95 percent confidence limits for several assumed values of P. For example, if one assumes

TABLE E-22

95 Percent Confidence Intervals for MSC Cycle Cost

P	PERCENT	CYCLE S.D.	LOWER	UPPER
.05	+/- 5%	175.0	23134.5	23820.5
.10	+/- 10%	350.0	22791.5	24143.5
.20	+/- 20%	700.0	22105.6	24849.4
.30	+/- 30%	1049.9	21419.6	25535.4
.40	+/- 40%	1399.9	20733.6	26221.4
.50	+/- 50%	1749.9	20047.7	26907.3

1. The standard deviation and the lower and upper bounds are in units of FY 84 $000s.

that the annual cost is no less than 50 percent of $4695.5 and no more than 50 percent higher than $4695.5 then the 95 percent confidence interval is $20047.7 to $26907.3 (FY 84 000s).

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