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STUDY OF HULL MECHANICAL/ELECTRICAL  
INSTALLED EQUIPMENT STANDARDIZATION  
FOR COMMISSIONED SHIPS

Task 66-6, Rev.

FINAL REPORT

JULY 1967

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## FOREWORD

During the past several years the Logistics Management Institute has conducted a number of studies directed toward achieving increased standardization within military weapons systems. LMI Task 65-13, initiated by Navy, was aimed at achieving increased standardization among Hull Mechanical/Electrical (HM&E) components and equipments (C/E) during new ship construction.<sup>1</sup> Following submission of LMI Report 65-13 during July 1965, the Chief of Naval Material requested that attention be directed to the possibility of achieving increased standardization of C/E already installed in active fleet ships. LMI Task 66-6 "Hull Mechanical/Electrical Installed Equipment Standardization for Commissioned Ships" resulted from that request.<sup>2</sup>

A progress report on Task 66-6 was submitted to the Chief of Naval Material on 31 March 1966. That report outlined a study approach for completion of the task, and suggested that some attention should be given to the feasibility of establishing rotatable pools of selected C/E for use during ship overhauls. The pool items could be used to support a remove and replace policy during overhaul in lieu of the more general current practice of remove, repair and replace, or repair in place. It was noted that a remove and replace policy had poten-

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<sup>1</sup>LMI Report 65-13, "Ships On-Board Repair Parts Outfitting and Revision of the Present Associated Supply Aids."

<sup>2</sup>See Exhibit 1, page 65, LMI Task Order 66-6, 19 August 1965.

tial benefit through shortening the length of time a ship spends undergoing overhaul, and, in addition, might possibly contribute to increased standardization of C/E installed in ships already in commission.

As a result of that Progress Report, the Director of Standardization and Configuration Management, NAVMAT, during August 1966, requested LMI to give priority to an in-depth study of the rotatable pool concept with the specific purpose of determining the potential contribution of the concept to increased component and equipment standardization. Task Order 66-6 was revised on 19 August 1966 to incorporate that supplemental effort.<sup>1</sup>

The supplemental effort dealing with the rotatable pool concept was given priority over the more general objectives of the basic task. An interim report covering rotatable pools was issued during January 1967.

This report is in two parts. Part A deals primarily with installed C/E standardization within classes of "in-service" ships; that is, the basic task called out in the original Task Order. Part B examines explicitly the rotatable pool concept and probes, in some detail, the interfaces between a rotatable pool program and a standardization program. Essentially, Part B is an incorporation into this report of the Interim Report of January 1967, with certain changes resulting from continuing discussions with concerned Navy organizations.

Each part of the report develops specific conclusions and recommendations for achieving C/E standardization and establishing

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<sup>1</sup> See Exhibit 2, page 66, LMI Task Order 66-6 (Revised), 19 August 1966. The supplemental effort is described in Paragraph B, subparagraphs 1, 2, and 3.

rotatable pools respectively. Both parts contain conclusions and recommendations which capitalize on mutual contributions from each program.

The effort leading to this report has required frequent and extensive discussions with representatives of industry and with numerous individuals in the Navy, both military and civilian. LMF wishes to express its appreciation for their cooperation, assistance and encouragement, without which the report would not have been possible.

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## PART A - EQUIPMENT STANDARDIZATION

### I. INTRODUCTION

#### 1. STANDARDIZATION DEFINED

For the purpose of this study, the act of achieving installed equipment standardization is defined as the process of reducing the number of different non-preferred components, to the extent economically feasible, within a group of functionally interchangeable components that currently are installed aboard in-service Naval ships.

There are three key requirements for achieving installed equipment standardization which are implicit in the above definition. These are:

- (1) The support environment must be specified.
- (2) Functional interchangeability among the components must be known.
- (3) A selection of preferred components must be made.

#### a. The Support Environment

The group of components considered for standardization action must have in common certain logistics support requirements. Without this thread of commonality among the components considered, there is little point in striving for increased standardization; in fact, efforts might better be directed toward product improvement of the individual components in their respective insulated support environments. Almost all components of a similar type, however, have some common threads of logistics support.

In the broad sense, all HM&E C/E<sup>1</sup> have common elements of logistics support. By definition, all components/equipments are repairables. Thus, there is maintained, either by the Navy or by industry, in the case of commercially repaired items, maintenance technical data, repair parts, tools and test equipment, and an inventory of skills capable of effecting repair.

In order to assess with reasonable accuracy the cost and benefit of effecting installed C/E standardization, it is necessary to define the support environment within which standardization is to be considered. For example, attention could be directed toward achieving increased standardization within the hull of a single ship. In such an event, benefits generally would be realized only on that ship in terms of the reduced maintenance capability that would be possible because of a reduction in the number of different components to be maintained aboard. Little benefit could be realized at the tender or shipyard level where the capability would have to be maintained in full for other ships of the Fleet that had C/E installed identical to that eliminated in the one ship subjected to intra-ship standardization. On the other hand, once intra-ship standardization has been achieved, the next step could be to standardize all ships of the same class, based upon the single ship standardization result. Still another approach would be to consider standardization of all functionally interchangeable components throughout the Fleet. In any case, the costs, benefits, and even the components selected as preferred items are likely to be different, depending on whether intra-ship, intra-class, or intra-Navy standardization is considered.

Although the techniques developed in this task are equally applicable to any level of support environment, our primary attention has been directed toward intra-class standardi-

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<sup>1</sup>The abbreviation C/E will be used throughout this paper to signify components and equipments and is not to be confused with cost effectiveness.

zation with the interpretation of class being somewhat broader than is normally allowed by Navy description.<sup>1</sup> In any event it should be recognized that a clear description of the support environment for which standardization is to be considered is a prerequisite to the analysis, application of techniques, and measurement of costs and benefits. Moreover, the selection of the most appropriate support environment toward which standardization efforts should be applied does itself require some feasibility analyses.

b. Functional Interchangeability Among Components

The second key requirement implicit in the above definition is that functional interchangeability among any group of different C/E considered for standardization must be known. This means that any preferred variety of C/E considered for replacing a nonpreferred variety must be capable of assuming the functional application of the latter without a sacrifice in performance. This does not mean that the preferred variety must necessarily be physically interchangeable with the component variety that is replaced; however, if not, the cost of achieving physical interchangeability must be established.

c. Selection of Preferred Varieties of Components

Finally, the definition implies that one or more varieties of functionally interchangeable C/E must be designated as preferred, and nonpreferred varieties must be identified. The preferred variety of component, however, does not necessarily have to be one of the varieties in the group currently installed.

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<sup>1</sup>For example, we would probably consider the entire fleet of SSBNs as a class while Navy definition would consider several ships built essentially from the same specifications as a class.

The preferred variety might be a more recently developed type of component of superior reliability to any of the currently installed varieties.

It is important to note that this part of the definition requires emphasis on the resultant economy of component reduction achieved and not merely on the quantity, and that only through such emphasis can we attain the ultimate objective of increased C/E standardization within in-service ships.

## 2. OBJECTIVES AND SCOPE OF BASIC TASK

The ultimate objective as stated in the Task Order is:

" . . . improvement in the logistics posture of the Fleet through economy in the repair and overhaul of ship components and through decreased ship out-of-service time for maintenance."

Part A of the task pursues this ultimate objective by examining the feasibility and methodology of achieving installed equipment standardization within classes of "in-service" ships. Stated more specifically, this part of the task has the following three principal objectives:

- (1) Describe the advantages of achieving installed equipment standardization.
- (2) Determine the feasibility of achieving installed equipment standardization.
- (3) Develop techniques for achieving installed equipment standardization, if feasible.

## II. FINDINGS AND ANALYSIS

### 1. ADVANTAGES OF ACHIEVING EQUIPMENT STANDARDIZATION

There are two principal areas of benefit which may result from achieving a greater degree of installed C/E standardization within in-service ships. The first and perhaps easiest to measure is decreased ownership costs associated with each preferred component that is used in lieu of a nonpreferred variety. The second area of potential benefit may generally be termed "increased readiness." Increased readiness to effectively perform an intended mission may be considered to prevail when there is a decrease in ships' down time, a condition which might reasonably be expected to accompany increased standardization. Each of these areas is discussed in the following paragraphs.

#### a. Decreased Ownership Costs

Ownership costs of a component is a term generally applied to the aggregation of costs associated with the operation and support of a given type of component performing a particular function. These are costs to perform a particular function that are over and beyond the initial purchase price of the component selected to do the job. Ownership costs include such things as: cost to operate the component, including--where appropriate-- personnel, fuel, and power; preventive maintenance; corrective maintenance; repair parts; supply management of both component and its repair parts; acquiring, operating, and maintaining required tools, handling and test equipment; documentation; training; and component procurement when the component has failed beyond repair.

Each variety of component selected to perform a particular type of function has associated with it its own peculiar ownership costs. In many cases, the cost of ownership will vary significantly for each variety of the same type component performing identical functions. Thus, standardization provides an opportunity to select a component which will result in lower ownership costs to the Government.

All elements of ownership cost have their fullest effect on total ownership cost at the time of initial component selection during ship construction. Since we are concerned with achieving standardization among components already installed aboard ship, certain elements of ownership costs have, for the most part, already been incurred. For example, documentation costs such as preparation of operating, maintenance and training manuals have been incurred. The cost of entering the component and its repair parts into the supply system has been incurred. Initial investment in repair parts and the acquisition costs of special tools, handling, or test equipment have also been incurred. It further should be recognized that certain elements of ownership costs generally are consistent with respect to certain types of components. For example, when considering Hull Mechanical/Electrical type equipment, there is generally little difference in costs among varieties of a given type component with respect to operating costs or training costs.

In conclusion, the most significant elements of ownership costs with respect to standardization of installed C/E are component replacement, preventive and corrective maintenance, and annual supply management costs. It will be useful to group these elements of costs into two categories: "support costs" and "supply costs."

(1) Support Costs. This category includes those elements of ownership costs which are a function of the number of component applications involved in the standardization action. The most significant elements of support costs are preventive maintenance, corrective maintenance, and component replacement. Each of these three elements represent some cost for each component application. Therefore, if one variety of component with low support costs is substituted for another variety with higher support costs, some economic advantage will result.

For example, suppose we have two varieties of a given type component installed on a single ship--variety X and variety Y. Table 1 illustrates the support costs for each variety in terms of dollars per year per component application. It will be noted that the support costs for variety X are \$145 per year per application less than the support costs for variety Y even though the purchase price of variety X is greater. If we standardize on variety X, an economic advantage with respect to support costs will result in the amount of \$145 per year for each X variety component that replaces a component of the Y variety. Since there are 40 applications of the Y variety in the illustration, replacing all 40 applications with the X variety component could result in \$5,800 per year less support costs.

The illustration cited above and in Table 1 is intended to demonstrate the relative economics of support costs between components having significantly different failure rates, repair costs, and condemnation rates. It should not be implied that such significant differences normally exist between any two varieties of a given type component. In many cases the difference between respective support costs associated with several different varieties of a given type component is insignificant. Moreover,

TABLE 1

ILLUSTRATION OF SUPPORT COSTS PER COMPONENT  
APPLICATION FOR STANDARDIZATION  
CONSIDERATION

	Component X	Component Y
Number of Component Applications - (e)	50	40
Failures (corrective maintenance actions) per year - (f)	10	16
Average repair cost per failure - ( $m_1$ )	\$ 200	\$ 250
Condemnation Rate (fraction of failures beyond repair) - ( $C_r$ )	.20	.25
Unit Purchase Price of Component - (U)	\$1200	\$1100
COMPONENT REPLACEMENT COST PER YEAR PER COMPONENT APPLICATION $\frac{(C_r)(f)}{e} (U)$	\$ 48	\$ 110
PREVENTIVE MAINTENANCE COST PER YEAR PER COMP. APPLICATION	\$ 90	\$ 130
CORRECTIVE MAINTENANCE COST PER YEAR PER COMPONENT APPLICATION $\frac{(f - C_r f)m_1}{e}$	\$ 32	\$ 75
SUPPORT COSTS PER YEAR PER COMPONENT APPLICATION	\$ 170	\$ 315



the illustration is not intended to imply that a single variety of a given type component should be designated as the only preferred component. In most cases a number of different varieties within a family of form/fit/functionally interchangeable components should be designated as preferred.

(2) Supply Costs. This category of ownership costs includes those elements which basically are a function of the numbers of different line items of supply associated with the nonpreferred types of components. Most significant in this category is annual supply management cost; i.e., the cost necessary to maintain a line item of supply in the inventory.

There are three levels at which supply management costs should be considered. First is the shipboard level where a cost is incurred in carrying each line item of supply aboard ship. Shipboard supply management costs should be considered when considering intra-ship standardization.<sup>1</sup> Second is the tender level. Supply management costs aboard the tender should be considered when undertaking intra-class standardization. Finally, there is the total Navy Supply System level. Supply management costs here represent the cost to carry a line item in the Navy Supply System and should be considered together with shipboard and tender supply management costs when examining intra-Navy standardization benefits.

In order to achieve standardization benefits from decreased supply management costs, complete line item elimination from the supply environment considered is required. Table 2

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<sup>1</sup>Supply management cost at shipboard level may be insignificant. At present no such cost has been established for either shipboard or tender levels. We believe that these costs should be established and considered if found to be significant.

TABLE 2

ILLUSTRATION OF STANDARDIZATION BENEFITS WITH RESPECT TO SUPPLY MANAGEMENT COSTS AT VARIOUS LEVELS OF SUPPLY

Component Variety	Number of Repair Parts Peculiar to Component	Component Distribution					Supply Management Costs (\$ per year per line item)
		Ship Class I				Ship Class II	
		Ship A	Ship B	Ship C	Ship D	Ship	
X	5	✓	✓	✓	✓	✓	@ shipboard level . . . \$20
Y	7	✓	✓	✓			@ tender level. . . . . 35
Z	9	✓	✓				@ Navy supply level . . . 100
Standardization Action							Resultant Savings from Supply Mgt. Costs (\$ per Year)
Eliminate all X components from Ship A							(5) (20) = \$ 100
Eliminate all X components from Ships A & B							5 [(20) (2) + 35] = 375
Eliminate all X components							5 [(20) (4) + (35) (2) + 100] = 1250
Eliminate all Y components							7 [(20) (3) + (35) (2) + 100] = 1610
Eliminate all Z components							9 [(20) (2) + 35 + 100] = 1575
Eliminate all X + Y components (Z is Standard)							1250 + 1610 = 2860
Eliminate all X + Z components (Y is Standard)							1250 + 1575 = 2825
Eliminate all Y + Z components (X is Standard)							1610 + 1575 = 3185

provides an illustration of standardization benefits resulting from decreased supply management costs when standardization is achieved at various levels.

Referring to Table 2, assume for illustrative purposes that it cost \$20 per year for supply management of each line item that is stocked aboard ship, \$35 per year aboard a tender, and \$100 per year at the Navy supply system level. Now, assume that we have three varieties--X, Y, and Z--of a given type component, all of which are functionally interchangeable, and that X, Y, and Z are installed aboard ships of the Fleet as indicated in Table 2. If all of the X variety of components are removed from Ship A and replaced by either Y or Z varieties, an act of standardization has been committed. In this case, the five repair parts which are peculiar to variety X are still required aboard ships B, C, and D, aboard the tenders which service Class I and Class II ships, and at the Navy supply depot. However, such repair parts are no longer required aboard Ship A. Thus, the act of standardization with respect to Ship A will result in a \$100 per year savings in supply management costs.

Using the example cited, Table 2 compares the savings from supply management costs which could be expected from various standardization actions.

b. Increased Readiness

Achieving greater C/E standardization within classes of in-service ships can lead to a decrease in equipment down time aboard ship, and hence an increase in ships' readiness. Although increased readiness is difficult to quantify, it is real and should be considered as a definite standardization benefit.

Increased C/E standardization contributes to increased readiness in four principal ways:

(1) Fewer Repairs. The preferred components normally should be selected because of higher quality or greater reliability. Thus, the preferred components generally should require less corrective maintenance.

(2) Less Repair Time. Fewer varieties of a given type component in service enables maintenance personnel to develop a greater expertise in both preventive and corrective maintenance practices. This expertise results in less time to identify cause of malfunction, and more efficient repair/overhaul procedures.

(3) Fewer Parts Shortage Delays. Accompanying fewer varieties of a given type component in service are fewer varieties of repair parts required. Since there is greater commonality among repair parts, there is less chance that delays will occur due to a shortage of repair parts. With a smaller range of repair parts required, the depth of required items could be increased with no increased cost or space. Thus a ship would be in a better position to support itself. A similar benefit accrues with respect to the General Stores Ships (AFS & AKS). Those ships cannot possibly carry a full range of repair parts for every C/E in the Navy. Increased standardization would allow the Stores Ships to carry a greater range of repair parts and thus reduce the number of such delays.

Another advantage of increased standardization is the associated increased mutual support that can be given by ships in company or in passing. For example, if all of a given C/E were standardized then a ship out of a repair part could obtain that part from another ship in company or passing.

(4) Greater Versatility in Maintenance Practices. Increased standardization of C/E makes it more economically feasible to employ the use of rotatable pools. A remove and replace

policy can in many cases contribute significantly to decreased ships' down time at all levels of maintenance.<sup>1</sup>

## 2. COSTS OF ACHIEVING EQUIPMENT STANDARDIZATION

### a. Investment Costs

In order to achieve installed equipment standardization on in-service ships, some investment generally is required. The amount of the investment depends on the number and unit price of the component involved, and the circumstances under which the nonpreferred components are replaced.

In determining investment cost, consideration should be given to the following five major factors:

(1) Acquisition Cost - Replacing a number of nonpreferred varieties of a given type component with an equal number of preferred varieties generally will require procurement of additional preferred components. The two exceptions to this are (1) where an excessive number of preferred components are currently available in the supply pipeline, and (2) when nonpreferred components in one class of ship have been designated as preferred components for another class. It is not anticipated that either of these exceptions would often prevail, but the latter should be considered as an alternative where acquisition costs are high.

(2) Component Removal Costs - This is the cost to remove each nonpreferred component from its installation so that a preferred variety may be installed.

(3) Engineering and Installation Costs - The replacement of a nonpreferred component with a preferred will always involve

<sup>1</sup>This aspect is covered in considerable detail in Part B.

some cost to install the preferred component. In some cases additional costs may be incurred; such as: (a) redesign of connectors, foundations, and housings; (b) opening and resealing certain areas required for installation accessibility; and (c) test and inspection of areas, components and connections affected by the installation.

(4) Disposal Value - The disposal value of each nonpreferred component should be determined and subtracted from investment costs to arrive at the net investment cost to achieve installed equipment standardization. The disposal value of a given component may range from its scrap salvage value to its full purchase price. The upper limit of disposal value would prevail when the nonpreferred component is to be used without alteration in some other environment which otherwise would require the procurement of a similar component.

(5) Replacement Circumstances - Finally, the circumstances under which a nonpreferred component is replaced by a preferred component should be considered in determining the net investment cost. Consideration should be given to the following questions:

(a) Will nonpreferred components be automatically replaced aboard ship, during tender availability, during restricted availability, during regular scheduled availability, or during an availability scheduled especially for purposes of standardization?

(b) Will nonpreferred components be replaced automatically if they require repair or overhaul? If so, at what level of maintenance?

(c) Will nonpreferred components be replaced only if they require repair or overhaul and the repair or overhaul costs exceed a given threshold?

(d) Over what period of time should the replacement operation be scheduled?

(e) What portion of the total number of nonpreferred components to be replaced will require repair or overhaul during the allocated replacement period?

(f) What is the anticipated condemnation rate (i.e., percent of failures beyond repair) for the nonpreferred components?

(g) Do the nonpreferred components to be replaced normally require removal or dismantling for repair or overhaul?

The net investment costs will depend to a large degree on the answers to the above questions. It should, therefore, be recognized that the investment cost can to some extent be controlled depending on the replacement schedule adopted. A methodology for selecting an appropriate replacement schedule is included in this report.<sup>1</sup>

b. Analytical Costs

Analytical costs will be incurred during the C/E standardization process, in addition to the investment costs already discussed.

If exhaustive economic and technical analyses are made with respect to all types of HM&E equipment currently in use, the analytical costs would undoubtedly be appreciable and could in fact be prohibitive. It is therefore necessary to minimize the analytical costs. This can be done by making initial simplified analyses which indicate areas of significant potential benefit and which capitalize on available data. Subsequently, more

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<sup>1</sup>See Appendix II.

detailed analyses can be undertaken for those areas of significant potential benefit. Some techniques for identifying those types of components with high potential benefit are included in this report.<sup>1</sup>

It should be recognized that while the decision methodologies developed in this report are specifically directed toward achieving installed C/E standardization, the type of data which is pulled into focus to support such decisions can also have significant value when applied to other areas of Navy management such as life cycle costing, maintenance planning and spare parts procurement.

### 3. FEASIBILITY OF ACHIEVING EQUIPMENT STANDARDIZATION

One of the principal objectives of this part of the study is to determine the feasibility of achieving installed equipment standardization. In responding to this objective our attention was directed toward the technical and economic aspect of standardization as well as the ability to maintain standardization once achieved.

#### a. Technical Feasibility

The technical feasibility of reducing the number of different varieties of any particular type components which are already installed hinges on two conditions being satisfied. First, there must be a reasonable degree of uniformity among the various performance requirements against which different varieties of a given type component are currently applied. This condition appears to be clearly satisfied. A study of the DDG-2 class, for example, indicated that out of 4,854 different HM&E components

<sup>1</sup>See discussion beginning on page 25 and Appendix I.



installed throughout the class, approximately 1,200 different components would have been sufficient to meet the performance requirements of all applications.<sup>1</sup>

A second condition is that nonpreferred components can be replaced without degradation to the operational performance of the system of which they are a part. This condition is generally satisfied with respect to HM&E type equipment, but may often be unsatisfied with respect to electronic or communication equipment where component compatibility is more sensitive.

Although installed equipment standardization with respect to HM&E type equipment is generally technically feasible, each case requires an engineering analysis and must be judged on its own merits.

b. Economic Feasibility

Achieving installed equipment standardization is economically feasible in those cases where the potential benefits accrued over a reasonable period of time exceed the required investment. The benefits and investment required are dependent on a number of factors such as: type of component considered; class, number, and age of ships considered; population distribution of components; overhaul or failure frequency of components; and acquisition and support costs of components. The economic feasibility of achieving installed equipment standardization, therefore, must be established on a case by case basis.

We have not determined the degree to which installed equipment standardization throughout the Navy is economically

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<sup>1</sup>LMI Task 66-11, "Standardization Objectives for FDL Ship Program," pp. 16-18.

feasible; nor have we attempted to identify those categories of components which offer the greatest potential. We believe, however, that economic analyses with respect to various categories of HM&E components installed aboard a selected class of ships would reveal that many such categories can very profitably be standardized. The results of such analyses might then be applied to other classes of ships throughout the Navy for similar categories of HM&E components.

While the investment costs to achieve installed equipment standardization may be high, the potential benefits appear to be impressive. For example, there are some 125,000 APLs (Allowance Parts Lists) in the Navy which have a population of less than 10 each. Each APL represents a different make or model of component. If only 20% of these were eliminated via standardization, there would be 25,000 less APLs in the supply system. A 20% reduction would appear to be conservative in view of the DDG-2 study mentioned above which indicated that 75% of the components installed in the class were technically feasible for standardization. Assuming that each APL has an average of three repair parts unique to that component, there would be 100,000 fewer components and repair parts to support in the Navy. It has been estimated that it costs the Navy \$100 per year per line item for Supply Management.<sup>1</sup> Therefore, the savings in Supply Management costs alone would be \$10M per year. If the 25,000 varieties of components had an average of three installations each, then 75,000 nonpreferred components could be replaced by an equal number of preferred components which would probably also result in additional support costs savings. It is pure speculation to say what these additional savings would be without identifying

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<sup>1</sup>This cost to manage a line item of supply per year currently is used for DoD Cost Reduction Accounting.

the types of components involved, but it is conceivable that an additional \$100 per year might be saved through decreased support costs. In this case, the savings over a 10-year period would come to \$175M less the investment cost. If we assume an average investment of \$1000 per unit, the investment cost is \$75M and hence the net benefits would come to \$100M.

In conclusion it would appear that the potential savings are large enough to warrant a continued effort to achieve installed equipment standardization among components currently installed in the Fleet.

c. Maintaining Standardization

No effort to achieve a greater degree of C/E standardization on in-service ships, regardless of how technically or economically feasible it might be, could be justified unless some means is provided to maintain standardization once achieved. Component proliferation after initial ship construction has occurred primarily because the desired component or its repair parts was not available at the time of ship's overhaul. One means of solving this problem is to establish, wherever feasible, rotatable pools to permit replacement in kind.

4. TECHNIQUES FOR ACHIEVING C/E STANDARDIZATION ON IN-SERVICE SHIPS

a. Navy's Current Standardization Program

The Navy has a dynamic standardization program underway. Although the Navy has long been concerned over the logistics support problems caused by the entry into the Fleet of nonstandardized ships, increased attention has been focused on the problem in recent years. Specific ship related standardization efforts are

proceeding in many areas, both with respect to new construction and to in-service ships. No attempt will be made to recognize all such efforts here; it is only desired to call attention to (1) Navy's organization for standardization management, and (2) to cite certain specific current efforts to improve the level of C/E standardization for in-service ships.

(1) Organization for Standardization Management -

The Navy Logistic Support Improvement Plan (NAVLOGSIP) of June 1965 appears to have served as the impetus for the current approach to ship C/E standardization. That plan established as one major objective that "The Chief of Naval Material determine the methods and techniques required to increase standardization of components and equipments."<sup>1</sup>

Subsequently, on 13 April 1966, the position of Director of Standardization and Configuration Management was established within the Headquarters, Naval Material Command. On 21 June 1966 OPNAV INSTRUCTION 4120.1, subject, "Standardization of New Construction, Conversions, Modernization and Alterations," was issued, a result of collaboration between NAVMAT and the OPNAV (OP36 - Ships Characteristics Division). Shortly thereafter, on 29 November 1966, NAVMAT INSTRUCTION 4120.97, subject, "Standardization of Components/Equipments (C/E) Required for Fleet or Ashore Support," was disseminated. Those two Instructions established Navy policy for standardization in ships and their C/E (as well as all Navy equipment), and together with the earlier establishment of a standardization focal point within NAVMAT Headquarters created a cohesive force for the furtherance of standardization.

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<sup>1</sup>Objective 10 of NAVLOGSIP--subsequently redesignated as Objective 11B.

Navy's current approach to standardization of ships' C/E has been expressed in terms of a short-range, mid-range and long-range plan as follows:

Short-range. To give visibility to ongoing standardization efforts and to establish basic standardization policy.

Mid-range. Further the use of existing equipment in new design.

Long-range. Promulgate and implement policies and requirements to restrict the acquisition of unneeded new items while backfitting to increase standardization on in-service ships.<sup>1</sup>

(2) Specific Current Navy Efforts - A number of programs are being pursued by the Navy to improve the level of C/E standardization on in-service ships.

(a) Replacing "Onesies." The single most revealing phenomena on the lack of C/E standardization in the Fleet is that of more than 170,000 different components/equipments installed in active Fleet ships, more than 47,000 of them are peculiar to one ship. Of the 47,000 peculiar items (those installed in only one ship) 52% are installed in 10% of the Navy's in-service ships as shown in Table 3, page 22.

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<sup>1</sup>For a fuller disclosure of the current Navy Approach, see NAVMAT P-4120 NAVLOGSIP Standardization, of September 1966.

TABLE 3

## DISTRIBUTION OF PECULIAR C/E IN SHIPS OF THE FLEET

Installed On	No. Ships	% of Total Ships	C/E Peculiar	% of Tot. Peculiar
Selected warships	74	6.5	15,676	33
Selected auxiliaries	<u>37</u>	<u>3.5</u>	<u>8,986</u>	<u>19</u>
Subtotal	111	10	24,662	52
All other ships	<u>1019</u>	<u>90</u>	<u>22,799</u>	<u>48</u>
Total	1130	100%	47,461	100%

NOTE: Data from NAVMAT (MAT 04C)

During the current overhaul of four selected ships, the AS-18, DD-889, CVA-62 and CG-10, specific treatment is being given to the peculiar C/E installed on those ships. Each peculiar C/E item has been identified and the overhauling shipyards are making determinations as to whether a more widely supported item of C/E should be installed at this time as a replacement for the peculiar items. Such determinations are based on such factors as operating condition of the peculiar item, maintenance and reliability experience, benefits to be gained in terms of increased support capability as a result of eliminating the peculiar item, availability of a more widely used item for replacement, etc. The experience gained from this pilot or test project will be used by Navy in formulating an all-out attack on the peculiar C/E in the Fleet.

(b) Selection of Preferred Items. In order to further the goal of C/E standardization in new construction, the

Navy has included in several recent shipbuilding contracts dollar incentives to motivate shipbuilders to use C/E that already is in use in the Fleet. In order to use that technique it is necessary for both the Navy and the shipbuilder to have visibility with respect to suitable, reliable in-use C/E. To date shipbuilders generally are permitted to select from C/E already in use in three or more ships of the Fleet.

Once such visibility of suitable, or preferred, in-use C/E is established, it also is useful to overhauling shipyards in selecting replacement items for the peculiar C/E identified as a part of the "Onesies" program discussed above.

(c) Procurement Techniques. In order to acquire replacement C/E identical to items already in use, Navy is more frequently using Life Cycle Cost procurement techniques. Logistics cost factors have been identified and promulgated for use by C/E procuring activities. Procuring activities, buying on a Life Cycle Cost basis, are thus better able to furnish to the overhauling activity C/E items identical or interchangeable with those in use.

In addition, the Navy Department has authorized procuring activities to limit competition to those makes and models of C/E currently in use and supported by the supply system, provided the purchase price of such C/E does not exceed \$2,500.

Using Life Cycle Cost procurement for replacement C/E should contribute substantially to the program for gradual elimination of peculiar C/E as well as make a solid contribution toward prevention of proliferation, during overhaul, of whatever standardization is achieved during new construction.

(d) Standardization Within Commodity Areas. At the same time efforts are being directed to C/E standardization on a ship and ship class basis, the problem is being attacked on a commodity basis. All HM&E C/E is stratified by the Navy into approximately 100 commodity areas, such as pumps, motors, control compressors, valves, etc. The following are typical of Navy activity to standardize on a commodity area basis:

1. Compressors. There are 900 different makes and models of compressors installed in the Fleet, of which 250 are peculiar; that is, used on only one ship. All compressors now are being reviewed in order to develop new compressor standards. It is intended that upon completion of the review specific guidance, as well as material requirements, will be developed for backfitting standardized compressors into the Fleet.

2. Motors. Of the 16,900 different motors and models of electric motors in the Fleet, 6650 are peculiar. A disciplined effort now is underway to reduce the different types and sizes of integral fractional horsepower motors and to designate interchangeability characteristics.

3. Valves. Of the more than 170,000 C/Es supported by the Navy, some 28% or 48,000 are valves. Twenty-three percent of the valves are peculiar. That situation is being attacked with a view to elimination of certain sizes and types, and to establish which valves should be considered throw-away, rather than reparable, items.

(3) Summary. The foregoing description of Navy's current effort is not intended to be all inclusive. Our visits to shipyards, procuring activities, engineering centers, and inventory control points indicate a wide-spread awareness, by personnel at all levels, of the need for achieving increased



C/E standardization. The program is well underway and continued top management interest, together with the development and implementation of more refined techniques for achieving C/E standardization in the active Fleet, will result in tremendous improvement in the logistics support of the Fleet.

b. Possible Additional Effort

The Navy has already made several notable strides in improving the component standardization posture of the fleet as discussed in the preceding section. These efforts should be continued. In addition, some techniques for possible use in accelerating the Navy standardization program are presented in the following paragraphs.

(1) Use of a "Component Standardization Index"

Standardization benefits and investments for different categories of components vary significantly. Investments required may be high and funds are definitely limited. Analytical and planning costs are not insignificant. In order to concentrate standardization efforts in the most profitable areas some measurement is required which can be applied to various categories of components.

A "Standardization Index" has been developed and is presented in Appendix I of this report. This standardization index represents a ratio of potential benefits to anticipated investment. The index is intended to be applied to various categories of components where such components are functionally interchangeable. In mathematical terms the standardization index may be stated as follows:

$$(S. I.) = K_1 \frac{N}{e} + K_2$$

- where
- $N$  = number of different varieties of a given type component
  - $e$  = the total number of installations of different varieties of a given type component
  - $K_1$  = a constant for the component category considered which represents the ratio of supply management benefits to investment, and
  - $K_2$  = a constant for the component category considered which represents the ratio of net benefits (exclusive of supply management) to investment.

In order to determine the index value for any given category of components, it is necessary to make several estimates.

These are:

- average number of repair parts per distinct component variety
- average supply management costs per year per line item (recent studies have shown this to be \$100)
- average investment cost per nonpreferred component replaced (see page 13 of this report)
- average savings in support cost per year for each preferred component used in lieu of a nonpreferred variety. (A comparison of maintenance costs would provide a reasonable basis for making this estimate since maintenance is by far the most significant support cost element.)

We believe that the required estimates can be determined with reasonable accuracy by knowledgeable Navy personnel.

It is intended that the Standardization Index be used for two purposes. First, to determine the optimum value of

N and e for each specific category of components. The methodology for these optimum values is developed and illustrated in Appendix I. Secondly, to establish priorities for achieving standardization with respect to specific categories of components.

(2) Selection of Preferred Components

In order to realize the fullest potential of standardization with respect to either in-service ships or new construction, the standard components must be carefully selected. The standard components should not only be limited to a minimum variety, but the varieties selected should be those that result in the most optimum balance between unit purchase price and total ownership costs. In selecting preferred components with respect to in-service ships, consideration should also be given to component and repair parts population distribution, disposal values, and engineering and installation costs.

The Navy is utilizing a preferred components list (developed primarily for the FDL and LHA ship systems); efforts will continue to improve the list through increasing the visibility of preferred components for design of new construction. To that end three techniques are suggested, as follows:

- Comparison of Relative Support Costs - The simplest method of selecting a preferred component from a group of similar varieties is to select the component with the lowest unit maintenance (preventive and corrective) costs per year. Corrective maintenance cost is generally the most significant support cost element. The exception to this is where specialized tools, handling or test equipment is required for corrective maintenance, in which case the operation and support of such equipment may be appreciable.

Corrective and preventive maintenance costs (including failure frequency and cost per failure) should generally be available from shipboard, tender and shipyard experience as well as from information compiled under the 3M (Maintenance and Material Management) system.

This method should be applied in those cases where no appreciable difference in unit purchase price, disposal value, and engineering and installation cost are anticipated with respect to the different varieties of components being considered.

- Comparison of Total Standardization Costs - The second method of selecting preferred components is to consider the total cost to the Navy if each variety of component in the group is selected as the preferred component. Appendix II develops a mathematical model for calculating the Cost Associated with Standardization ( $C_s$ ) which is summarized in Equation (8) of the Appendix. The approach is to calculate the  $C_s$  value for each component variety being considered and select the one or several with the lowest values.

This approach is more exacting but results in considerably greater analytical costs than the first approach. It should be used therefore only in those cases where the potential standardization benefits are high and appreciable differences are anticipated with regard to unit purchase price, disposal value, and engineering and installation costs.

- Life Cycle Cost Procurement - The third method is similar to the second one described above except that consideration is given to the introduction of a new variety of component into the system as the preferred component. This approach should be considered when there is a general dissatisfaction with the performance of all varieties in the group or in cases where recent

advances in the state-of-the-art have occurred with respect to the types of components being considered.

(3) Methodology for Developing the Replacement Schedule

Once standardization among a group of similar type components has been generally justified and the preferred components have been indicated, a replacement schedule should be developed. This replacement schedule should be developed with consideration for minimizing the investment costs and taking full advantage of scheduled ships availabilities. An analytical model to assist in the development of a replacement schedule is presented in Appendix II.

(4) Providing a Standardization Budget

Standardization among components which are currently installed aboard in-service ships cannot be achieved without considerable investment. Under the present situation there are no funds available which are directly allocated to this purpose. Without such funds it is doubtful that the standardization effort can be accelerated. It is suggested, therefore, that consideration be given to allocating specific funds in the budget to Standardization Investments. The amount of such funds can be determined and justified by use of the "Standardization Index" already discussed.

(5) Interfacing With Rotatable Pools

Part B of this report examines in some detail the interfaces between standardizations among a group of similar type components and the establishment and use of rotatable pools with respect to such components. These interfaces will not be discussed here except to state that achieving standardization among a group of similar type components will undoubtedly

increase the probability that such components can be justified as applicable to the rotatable pool concept. Thus, the extent to which standardization can be achieved prior to establishing rotatable pools will enhance the benefits achievable via the rotatable pool concept.

The rotatable pool concept offers its own unique type of benefit: namely, shortened ships availabilities. This benefit is discussed in detail in Part B of the report. Generally, once a rotatable pool has been justified, it should be established and put to use as early as practical. The only exception to this is when the particular components which have been justified as applicable to the rotatable pool concept are suspected of being or becoming nonpreferred varieties for future use. Even in these cases it may be economically advantageous to establish the rotatable pool as early as practical, depending on the magnitude of benefits achievable. In these cases a brief standardization assessment could aid in making the decision to establish the rotatable pool immediately or defer its establishment until a standardization analysis had been conducted and the results implemented. The criteria for such a brief assessment would be limited to: (1) the estimated time required for a standardization analysis and implementation;<sup>1</sup> (2) the potential rotatable pool benefits accruable during the time estimated above; and (3) the estimated investment loss in pool components.

Appendix IV develops a decision model for determining whether it is more economically advantageous to achieve a greater degree of standardization among a group of similar type components before establishing the rotatable pool concept. It should be recognized that this decision is only pertinent when

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<sup>1</sup>An average time of two years might reasonably be assumed and applied in all cases.

the components under consideration are suspected of being or becoming nonpreferred for future use.

### III. CONCLUSIONS AND RECOMMENDATIONS

#### 1. CONCLUSIONS

Standardization of C/E already installed in ships of the Fleet is a very different and, in some respects, more difficult problem than achieving increased C/E standardization in new ship construction. In pursuing standardization in new construction, the major task is to develop procurement methods that result in the shipbuilder delivering standardized ships. The benefits of such a result are wide ranging. However, when considering standardization of installed C/E, certain new construction standardization benefits cannot be realized because the investment already has been made in such items as data, repair parts, spares, and special tools and test equipment. Thus, when determining what installed C/E should be standardized, the economic benefits essentially are limited to maintenance costs over remaining life and supply management costs avoided through removal of items from the logistic support system. Increased readiness benefits do accrue but are not quantifiable; they cannot be incorporated into a C/E standardization decision model.

In spite of the above, it is believed that standardization of installed C/E should continue as a primary goal of the Navy because of the extensive proliferation of makes and models of C/E now being supported. It would be possible to eliminate many of these different makes and models by relying upon new construction standardization; however, many years would pass (at least an amount of time equal to the life of the existing fleet) before the goal was attained. Moreover, since the current new construction emphasis calls for selection of C/E already supported in the



Fleet, it is important to compress the number of choices available to the shipbuilder. Standardization of installed C/E, to the extent that the process identifies preferred items, will assist in compressing the number of choices available.

Working to achieve optimum standardization is a complex task. Too much emphasis on standardization can result in economic losses because achieving identity of hardware usually necessitates some sacrifice in the most economic approach to satisfying specific functional requirements. Technological progress and competition in procurement can be unnecessarily impeded by overemphasizing standardization. Underemphasis, on the other hand, can result in excessive support costs. Thus, achieving installed C/E standardization presents some complex problems and no simple solution is in the offing.

The Navy has begun to attack the problem of installed C/E proliferation. Progress is being made. It is believed that the Navy's effort should be intensified, and that such intensification should be based on a carefully derived approach. Such an approach to the problem is necessary because of the peculiarities associated with standardization of installed C/E.

Specific conclusions that have been reached as a result of this study and that underlie the more generalized statement in the above paragraphs are as follows:

Conclusion 1 - Standardization of currently installed C/E is feasible only with respect to certain components and only under certain replacement conditions, and therefore must be justified on a case by case basis.

Conclusion 2 - Because of the very nature of standardization benefits (i.e., increased readiness and decreased supply management and component support costs), a uniform analytical approach

with respect to various ships and classes is required if maximum potential benefits are to be achieved.

Conclusion 3 - Achieving increased installed C/E standardization requires considerable analysis and planning effort, including:

- a) identification of functionally interchangeable components,
- b) selection of preferred components,
- c) economic tradeoff analyses and scheduling for component replacement, and
- d) acquisition planning for required additional components.

Conclusion 4 - Selection of preferred components should be based on a disciplined approach with consideration given to:

- a) relative support costs,
- b) remaining years of service application,
- c) purchase price of required additional preferred components and disposal value of nonpreferred components, and
- d) the relative ownership costs of a new high quality or highly reliable component if introduced as the preferred component.

Conclusion 5 - A more disciplined approach in the selection of preferred components will provide a more effective basis for achieving component standardization in new ship construction as well as in existing ships.

Conclusion 6 - Analytical and planning costs required to justify and implement installed C/E standardization are generally high enough to require some initial indication that standardization benefits are possible with respect to specific groups of components in specific support environments. Therefore, some measurement is required which will indicate relative ratios of benefits to investment before undertaking an exhaustive standardization analysis.

Conclusion 7 - Due to extensive planning, procurement and installation work required to justify and implement standardization, the scheduled availability of a ship appears to provide the best opportunity to achieve installed C/E standardization among in-service ships.

Conclusion 8 - Except for the selection of preferred components, standardization benefits are generally best achieved by eliminating from any group of functionally interchangeable components those which have a single application first, then those which have two applications, etc.

Conclusion 9 - Installed C/E standardization among in-service ships cannot be achieved to its fullest potential unless specific funds are allocated for the purchase of additional preferred components.

## 2. RECOMMENDATIONS

Recommendation 1 - It is recommended that the Navy develop a formal program for retrofitting, where economically feasible, Component/Equipment (C/E) standardization into the existing fleet, and that the program include policies and procedures for:

- a) establishing priorities by component groupings,
- b) designating preferred components,
- c) establishing replacement schedules, and
- d) establishing standardization budgets for the procurement of required preferred components.

Recommendation 2 - It is recommended that the Navy develop and apply a "Standardization Index" which will reasonably approximate benefits to investment ratios for specific component categories, and that such an index be used for:

- a) establishing priorities by component categories for achieving retrofit Component/Equipment standardization, and
- b) establishing goals as regards the extent to which retrofit C/E standardization should be achieved.

Recommendation 3 - It is recommended that component categories having a high "Standardization Index" be evaluated for component replacement at the time of scheduled availabilities of the ships on which such components are installed, and that component replacement schedules be developed from these evaluations. It is further recommended that these replacement schedules be used as a basis for establishing standardization budgets.

Recommendation 4 - It is recommended that interchangeability be established by commodity groupings, designating the preferred components contained therein, in accordance with the priorities determined by the "Standardization Index."

Recommendation 5 - In supplementing the above recommendations, it is recommended that a test case, limited to a single class of ship, be initiated to establish the validity and usefulness of the methodologies presented in this report, including the "Standardization Index" and the "Component Replacement Schedule."

Recommendation 6 - It is recommended that a replacement policy statement be issued at the earliest practical date which would encourage replacement by a preferred component of any non-preferred components which require repair at the time of scheduled availability and the repair cost approaches replacement cost.

While Recommendations 1 - 5 are directed toward achieving the fullest standardization benefits, implementation will require time and investment. Recommendation 6, on the other hand, is directed toward initiating standardization action immediately, at the lowest possible cost.

## PART B - ROTATABLE POOLS

### I. INTRODUCTION

During August 1966, the Director of Standardization and Configuration Management, NAVMAT, requested LMI to concentrate its effort on the rotatable pool concept with the specific purpose of determining the potential contribution of the concept to increased component and equipment standardization. Task Order 66-6 was revised on 19 August 1966 to incorporate that supplemental effort.<sup>1</sup>

An interim report on that effort was submitted during January 1967. The report concluded that rotatable pools of HM&E components and equipments offered some promise in helping to sustain whatever level of standardization could be achieved during a ship acquisition program, but that the significant potential benefit of rotatable pools was in the area of decreased ship out-of-service time.

The interim report received limited distribution and has served as a vehicle for discussion between LMI, NAVMAT, and NAVSHIPSYSCOM. As a result of those discussions we have made some changes in the interim report and are submitting in this Part B our final report on the supplemental task.

The supplemental effort, reported on in this Part, was directed to three areas of investigation, as follows:

#### 1. Rotatable Pools and Standardization

The study first examines the interfaces between the process of establishing and using a rotatable pool of components

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<sup>1</sup>See Exhibit 2.

and the process of achieving a reduction in the variety of such components installed in ships of the Fleet. The interfaces are examined in terms of benefits, costs, and timing associated with each process. The objective is to determine the potential contribution of the rotatable pool concept to increased component standardization. Stated another way, the objective is to determine the proper relationship between a standardization program and a rotatable pool program as such programs contribute, singularly or collectively, to overall improvement in the logistics posture of the Fleet.

## 2. Methodology for Selecting Rotatable Components

Second, the study develops a decision method for selecting components to be included in a rotatable pool. The decision methodology considers the three levels of ship maintenance: shipboard, tender, and shipyard.

## 3. Organization for Component Repair

The third aspect of the study is concerned with the question of single vs. multi-overhaul points for components, once a rotatable pool has been justified. The objective is to consider in the development of a rotatable pool methodology the number of overhaul points for a given type of component where the rotatable pool concept is justified.

## II. FINDINGS AND ANALYSIS

### 1. ESSENTIAL ELEMENTS OF A ROTATABLE POOL

The rotatable pool concept consists of providing a pool of components which can be exchanged with in-use components when such in-use components require repair or overhaul, overhauling the removed components at an appropriate time, and replenishing the pool with the overhauled components. There are three essential elements associated with establishing a rotatable pool: (1) interchangeability, (2) pipeline requirements, and (3) mode of repair.

#### a. Interchangeability

Knowledge of the interchangeability characteristics of installed shipboard equipments/components is required in order to determine the feasibility of establishing a rotatable pool. Interchangeability determines the population of any particular component or group of components to be supported.

Before assessing the costs and benefits of establishing a rotatable pool, it is first necessary to identify the candidate components in terms of their capability of being interchanged. If the components under consideration are not interchangeable in form, fit, and function, then the components in the rotatable pool are not available for exchange with similar type components requiring overhaul without incurring additional installation costs or without sacrificing either component performance or acquisition cost.

At this time the highest grouping of HM&E equipments/components that can easily be classified as interchangeable are



those bearing the same Component Identification Number (CID); in other words, those that are identical as to make and model. There is no way, short of a technical analysis on a case by case basis, of determining whether a 5HP, 3-phase, 60-cycle, 440-volt motor with a given CID can be interchanged with a motor of the same characteristics but carrying a different CID number.

b. Pipeline Requirements

The second essential element in determining the feasibility of a rotatable pool is the number of additional components required to stock the rotatable pool. It is necessary to calculate the size of the pipeline with some precision because it may represent a considerable investment, and once a rotatable pool is established it must always be in a position to support the maintenance concept upon which it was based. The pipeline size is dependent on two principal factors: (1) the total number of components overhauled per year, which we refer to as the frequency of overhaul; and (2) the overhaul or supply turnaround time.

The number of components required in the rotatable pool may generally be determined by the product of the "frequency of overhaul" and the "turnaround time." In some cases, however, this product may be insufficient for the initial application of the rotatable pool due in overlapping or concurrent ships' overhaul. In such cases, consideration should be given to increasing the size of the rotatable pool.

(1) Frequency of Overhaul

The number of overhauls per year of a given type of component is dependent on a number of things, such as component reliability, population, and preventive maintenance practices.

These factors must be considered for each level of maintenance where the frequency of repair is being considered.

For example, if a rotatable pool concept is being considered at shipboard level, then the frequency of overhaul may be described as the product of the component failure rate times the shipboard component population. On the other hand, if a rotatable pool concept is being considered at the shipyard level for regularly scheduled overhauls, then the frequency of component overhaul is dependent not only on component reliability characteristics and component Navy-wide in-use population, but also on the extent to which the ship's crew can and does perform corrective maintenance before scheduled overhaul.

Thus, the frequency of repair or overhaul must be geared to the level of maintenance at which the rotatable pool concept is considered.

## (2) Turnaround Time

As in the case of the frequency of overhaul, turnaround time is dependent on the level of maintenance supported by the rotatable pool. At the shipboard level, the turnaround time would be (1) the time the ship is self-sufficient; that is, the time the ship must operate from its on-board rotatable pool between resupply action; or (2) the time the ship can sustain its rotatable pool through on-board overhaul of removed components; or (3) a combination of (1) and (2). At the shipyard level, in support of regularly scheduled ship overhauls, the turnaround time is the time required, starting with the date of removal, to overhaul a component and return it to stock, ready for issue.

c. Mode of Repair/Overhaul

The mode of repair is the level of maintenance at which the components resupplying the rotatable pool are repaired (e.g., shipboard, tender, or shipyard); the type of personnel used to make the repair (e.g., ship's crew, tender crew, shipyard personnel or contractor personnel); the methods of repair (e.g., single units as received or batch lots of predetermined quantities); and the number of repair activities used. The mode of repair has an impact on the frequency of repair and the repair turnaround time which, in turn, determines the additional pipeline investment required. The mode of repair may also affect the unit repair cost of the component. Thus, it is essential that the mode of repair be considered in determining the feasibility of establishing a rotatable pool of any given group of components.

2. POTENTIAL BENEFITS OF A ROTATABLE POOL

There are three principal areas of potential benefit to be derived from the rotatable pool concept. The area that offers the greatest potential is shortened ships' availabilities or decreased ships' out-of-service time for overhaul. A second area of potential benefit is a reduction in certain "ownership" costs associated with those components which feed into and out of the rotatable pool. Finally, there are the standardization benefits which accrue through the prevention of component proliferation during ships overhaul. Each of these areas is analyzed in some detail in the following paragraphs.

a. Shortened Availabilities

The use of rotatable components would, under certain conditions, result in shortened ships availabilities, regular,

restricted and tender. Although it is possible to apply the rotatable pool concept at the shipboard level and, on occasion, realize decreased ship downtime, it is more probable that downtime advantages would accrue from using the concept at the tender or shipyard level.

A rotatable pool can contribute to shortened availabilities because it releases the ship from its ties to the installed components on the ship at the start of an availability. Thus, the length of the availability would not be dependent upon the time required to overhaul components. For example, Table 1 shows three actual cases (taken from naval shipyard records) where the time to exchange components, that is, remove and replace with a ready-for-issue (RFI) unit, is compared with the time to remove, overhaul and replace the same component.

In order for the decreased elapsed time to be meaningful, the elapsed time under the Remove, Overhaul and Replace (RO&R) concept must control or contribute to the control of the availability time. Justification of any increased cost to establish and maintain a rotatable pool requires that the decreased elapsed time must have a value in excess of the difference between the total cost under the remove, overhaul and replace (RO&R) concept and the total cost under the remove and replace (R&R) concept.

TABLE 4

COMPARISON OF COMPONENT REMOVE & REPLACE (R&R)  
VS. REMOVE, OVERHAUL AND REPLACE (RO&R)

Component	R&R Elapsed Days	RO&R Elapsed Days
MK NC-2 Plotting Equipment	15	70
AN/GRC-27A Transceiver	2	73
MK11, MODG Gyro Compass	10	52

(1) Ways of Controlling Length of An Availability

There are several ways by which rotatable pools can contribute to shortened ship availabilities. First, a specific type of component could directly control the availability. Suppose, for example, that the Gyro Compass (Table 1) was the only component requiring repair and hence caused a restricted availability. In such a case the restricted availability time could be reduced by 42 days if an RFI component was available for immediate installation.

In some cases a single component could control the length of a regular availability, although perhaps not so significantly as in a restricted availability. More often, the combination of many components would control the length of a regular availability. A second way, then, whereby a rotatable pool could shorten availabilities is where an aggregation of component overhaul work is controlling. Suppose, for example, that a rotatable pool could be justified for the Gyro Compass (Table 4), but, due to high investment cost in additional pipeline, the other two components could not be justified as rotatable spares. Suppose further that overhaul labor skills are limited but interchangeable among all three components. In such a case, the overhaul labor available by deferring the overhaul of the Gyro Compass might be applied to the overhaul of the other two equipments, thus reducing the elapsed time for their overhaul.

In many cases, the length of a regular availability is controlled by ship alterations (Ship Alts), not regular overhaul work. Still the rotatable pool concept could contribute to shortened availabilities by using the labor saved by deferring component overhaul to the controlling alteration work.

A number of specific cases have been identified in the course of this study where the application of a rotatable pool concept could have resulted in shortened availabilities. Although no specific types of components that consistently control could be identified, findings indicate that there are a number of components which collectively represent a repair workload that could be controlling.

(2) Value of Shortening An Availability

In order to determine the feasibility of establishing a rotatable pool, it is necessary to establish the value of a shortened availability. In a few cases the Navy has assigned a value of a mission-ready day to classes of ships. Such values range from a few thousand dollars per day to over a hundred thousand dollars per day. In determining the value per day, such things as acquisition cost, operating cost, and maintenance cost have been considered over the anticipated life of the ship. These figures may, however, be too liberal for our purpose.

For the purpose of establishing a basis for appraising the value of shortened availabilities the investment value per day of a ship can be determined by dividing the acquisition cost of the ship, including all its equipment that must function as an integral part of the ship's mission, by the anticipated service life of the ship in days. Operating and maintenance costs are specifically excluded because the concern is with the economic value per day of a ship's capability to perform its intended mission, not with the operating cost of performing the mission or with the value of the mission.

(3) Magnitude of Potential Benefits for Shortened Availabilities

Since the work package required at each overhaul is different and since the controlling factors may vary with each overhaul, it is difficult to identify on a total Fleet basis the potential benefits achievable through the rotatable pool concept as it might contribute to shortened availabilities. However, the order of magnitude of such benefits may be approximated by estimating an average percent decrease in scheduled availabilities that could reasonably be expected through application of a rotatable pool concept.

Table 5, page 48, was developed using the above approach. The investment cost per day represents the acquisition cost of the ship or classes of ships divided by an assumed twenty-five year life less the number of days the ship now spends in a regular availability. The approach is rough; restricted and interim availabilities are ignored as well as alteration and conversion costs. The purpose here, however, is to develop an approximate value which is within reason. Thus, it would appear that appropriate application of the rotatable spares concept could conceivably result in some \$38 million dollars per year savings in terms of shortened availabilities if a 25% decrease in regular overhaul time is assumed.

b. Reduction in Component Ownership Costs

This, the second area of potential benefit from use of a rotatable pool in support of overhauls, is concerned with decreased ownership costs associated with the components that are fed into, and feed out of, the rotatable pool. Ownership costs include such things as: component replacement when the component

**TABLE 5**

**ILLUSTRATION OF THE EFFECT OF SHORTENING LENGTH OF TIME IN OVERHAUL, SELECTED SHIP CLASSES**

Ship Category	Approx. No. of Ships per Cat.	Acq'n Cost Per Cat. \$M	No. Ship O/H Days Per Year	Avg. Value per Day of Ships Avail. by Category	Approx. Value per Yr. of Ship O/H Time	Potential Savings 25% Reduction in O/H Time
CVA (MODERN)	8	\$ 2,039	446	\$ 33,241	\$14,825,486	\$ 3,706,371
CVA (MIDWAY)	3	263	176	11,447	2,014,672	503,668
CVA (HANCOCK)	5	260	294	6,793	1,997,142	499,280
CVS	10	948	588	12,384	7,281,792	1,920,448
SSN	39	2,686	3,931	10,427	40,988,537	10,240,000
SSBN	41	4,419	3,247	15,084	49,385,016	12,346,254
CGN	1	331	36	40,243	1,448,748	362,187
DLG	28	1,738	941	7,492	7,049,972	1,762,493
DDG	23	875	676	4,534	3,064,984	766,246
ALL OTHER	742	7,139	21,370	1,145	24,468,650	6,117,162
<b>TOTAL</b>	<b>900</b>	<b>\$20,698</b>	<b>31,705</b>		<b>\$152,524,999</b>	<b>\$39,131,249</b>



is beyond repair; repair parts; preventive maintenance; corrective maintenance; supply management; acquiring, operating and maintaining required tools, handling and test equipment; documentation; and training. Although a rotatable pool may tend to reduce each of the ownership costs, the most significant potential benefits are: (1) economic overhaul; (2) quality of repair; and (3) requirements for repair parts, tools and test equipment.

(1) Economic Overhaul

Perhaps the most direct and significant reduction in ownership costs resulting from the rotatable pool concept is a more economical overhaul of the components participating in the pool. Such benefits are achieved primarily by batching the components in economic repair quantities.

The potential for improvement in this area, however, is relatively small in comparison with the potential for shortening the length of an availability. Table 6 shows the actual direct labor hours and the cost during FY1966 at the nine naval shipyards for repair work only in Shops 31, 38, and 51, those shops most likely to be repairing HM&E components susceptible to being designated as rotatables. As seen from the Table, only some \$52M were expended in this area.

Assuming that 50% of the workload of the three shops is directed toward the overhaul of components feasible of becoming rotatable spares, a 10% decrease in repair costs through batching amounts to only some \$2.5M per year. The net benefit would, of course, be determined by the additional investment in pipeline necessary to make the rotatable pool concept work.

Another benefit of batching deserves mention. Batching tends to discipline the planning for overhaul so that

TABLE 6

SHIP REPAIR WORK FOR SELECTED WORK CENTERS  
 FY 1966 ACTUAL <sup>a</sup>

	MACHINE SHOP Shop 31		MACH. (MARINE) SHOP Shop 38		ELECTRIC SHOP Shop 51		TOTAL for Shops 31,48,51	
	HOURS (in Thousands)	DOLLARS (in Thousands)	HOURS (in Thousands)	DOLLARS (in Thousands)	HOURS (in Thousands)	DOLLARS (in Thousands)	HOURS (in Thousands)	DOLLARS (in Thousands)
PORTSMOUTH	138	566	218	879	166	669	522	2,114
BOSTON	158	694	175	761	107	467	440	1,922
PHILADELPHIA	374	1,601	656	2,820	672	2,945	1,702	7,366
NORFOLK	695	2,902	721	2,983	602	2,453	2,018	8,338
CHARLESTON	221	890	248	1,049	230	958	699	2,897
LONG BEACH	493	2,271	346	1,582	271	1,194	1,110	5,047
SAN FRANCISCO	1,172	5,359	1,137	5,144	858	3,918	3,167	14,421
PUGET SOUND	235	1,051	299	1,327	158	694	692	3,072
PEARL HARBOR	529	2,255	578	2,499	506	2,224	1,613	6,978
TOTAL	4,015	17,589	4,378	19,044	3,570	15,522	11,963	52,155

<sup>a</sup> Labor cost is calculated on a weighted rate per hour to include a sick and annual leave. No other form of overhead is included. Does not include work for SHIPALTS, ORDALTS, CONVERSION, etc.

required repair parts are available when needed. This can result in considerable savings in both procurement and manufacturing costs. For example, one shipyard has reported that during the recent overhaul of an aircraft carrier it was forced to manufacture 3,820 repair parts because the parts were out of stock and could not be procured in time. The manufacture of those repair parts cost an estimated \$260,000 over and above the cost had they been procured from industry.

(2) Quality of Repair

It is the consensus of most ship maintenance personnel with whom we have consulted that items in a rotatable pool would receive a higher quality overhaul than the same components receive under the present job-shop type overhaul. There are several reasons cited in support of that position:

(a) The planning necessary to sustain a rotatable pool would tend to improve the availability of repair parts, thus assuring that a more complete overhaul could be accomplished.

(b) Removing the concurrency time pressure of component overhaul would inhibit the tendency for the "quick fix" or minimum type attention that often is given a component when its overhaul time requirement is responsible for delaying the completion of an availability.

(c) Repetitive overhaul of a given component, or a family group of components by an activity, particularly when the components can be batched, enhances the knowledge and skills of the overhauling personnel. Such a result contributes to increased quality (in addition to more direct economies cited under economic overhaul above).

### (3) Tools and Test Equipment

Under certain conditions a rotatable pool can contribute to economic gains by reducing the investment and the cost of operating and maintaining tools and test equipment required to support component overhaul. One such condition would exist when the components feeding the rotatable pool are overhauled at a single installation rather than at multi-installations. These types of savings probably are nominal with respect to ships mechanical/electrical components, in contrast to those generated with respect to electronic components that require sophisticated tools and test equipment for overhaul.

#### c. Standardization

Component standardization is defined as a reduction in the number of makes and models of components serving identical functions. This, the third area of potential benefits to be derived from use of a rotatable pool concept, is a difficult area to assess.

It is recognized that the existence of rotatable pools would greatly assist in sustaining that level of standardization attained during a ship acquisition program. For example, a rotatable pool would lessen the frequency of installing a different make or model during overhaul when a replacement for the installed variety, or repair parts to overhaul it, are not available. The frequency with which such action takes place has not been determined; all ship maintenance personnel interviewed cite it as a problem and we have confidence that its impact is a major one. While it is clear that rotatable pools could assist in this area, it must be recognized that the problem could be lessened through other improvements in material planning for ship overhauls.

Achieving a reduction in the variety of installed components through use of a rotatable pool is unlikely. To use a rotatable pool for such a purpose would require that the entire variety of components are interchangeable or that the cost of making the components interchangeable has been justified. In addition, the size of the rotatable pool is determined by the population of the components it supports, so that a demand on the pool for components whose applications were not initially considered in establishing the pool would result in depletion of the pool.

The interfaces of the rotatable pool concept and standardization presents some complex problems which are discussed in more detail in the subsection following.

### 3. INTERFACE OF ROTATABLE POOL CONCEPT AND STANDARDIZATION

#### a. Benefits and Costs<sup>1</sup>

As discussed in the preceding paragraphs, it appears that the major benefit achievable through the establishment and use of rotatable pools are those associated with shortened availabilities. Standardization makes no direct impact on shortened availabilities. Indirectly, standardization makes it more likely that repair parts will be on hand at time of ships' overhaul and hence result in shortened availabilities. Also, standardization may indirectly result in shortened availabilities in that increased reliability generally accompanies a standardization achievement, but such benefits are difficult to assess.

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<sup>1</sup>It should be recognized that the benefits and costs of achieving standardization described in this report are directed toward in-use HM&E components and do not apply to achieving standardization during new ship construction. For discussion of the latter concept, see LMI Reports 65-13 and 66-11.

Standardization, however, does have a more significant impact on ownership costs than does the rotatable pool concept. The rotatable pool concept tends to reduce such costs, primarily through a reduction in the unit repair cost. Standardization not only decreases corrective maintenance costs but generally has a more beneficial effect on all other elements of ownership costs.

Perhaps the most significant economic benefit of standardization is a decrease in supply costs, including supply management, parts inventory, transportation, handling and storage. Such decreased costs result from fewer varieties of components and parts required in the supply system. The rotatable pool concept, on the other hand, may result in increased supply costs in that additional transportation, handling and storage may be required to facilitate multi-unit repair and maintain the rotatable pool.

The investment required to achieve standardization is generally much greater than the investment required to establishing rotatable pools. For example, suppose there are three functionally interchangeable varieties of a particular type of pump, each having an overhaul frequency of 8 overhauls per year and each having an overhaul turnaround time of 3 months.

The size of the rotatable pool for each variety (assuming an even distribution of the overhaul frequency) would be  $8 \times .25$  or 2 pumps. Thus, 6 additional pumps would be required to establish a rotatable pool for all three varieties. Now if each variety requires 8 overhauls per year, it would be reasonable to assume that the number of pump installations which contribute to such an overhaul frequency would be in excess of 8 installations. To be conservative, however, suppose that each of the three varieties have 8 installations. Now, if through a standardization

action one of the three varieties was used in lieu of the other two, then 16 additional pumps would be required.

A standardization analysis to identify a limited variety of components preferred for further use is considerably more complex and time consuming than an analysis to determine the feasibility of using rotatable pools. Moreover, the standardization analysis requires engineering competence and technical data which are not always readily available, whereas a rotatable pool analysis generally can be made by nontechnical personnel on the basis of existing knowledge.

Achieving standardization among current in-use components often involves considerable additional costs in design changes and modification or installation work. Establishing a pool of rotatable components, on the other hand, does not include these types of costs since the ability to establish such a pool is predicated on the premise that the components constituting the pool are interchangeable in form, fit, and function.

b. Sequencing Effects

If a rotatable pool concept is applied to a group of similar but different components and that group of components later is subject to a standardization analysis which indicates that it is economically advantageous to replace all nonpreferred components in the group with one preferred variety, then the establishment of the various rotatable pools will result in some economic loss. Table 7 illustrates the significance of such a loss.

Assume there are ten different varieties of a given type of component, (a) through (j), with different populations

TABLE 7

ILLUSTRATION OF STANDARDIZATION EFFECT ON COMPONENT ACQUISITION FOR ROTATABLE POOL

COMPONENT	COMPONENT POPULATION	STANDARDIZATION ACTION (* INDICATES STANDARD ITEM FOR COMPONENTS IN BRACKETS)	TOTAL REPAIRS PER YEAR		REPAIR TURN-AROUND TIME (YEARS)	NUMBER OF ADDITIONAL COMPONENTS REQUIRED			COMPONENTS NOT REQUIRED IF STAND'Z. OCCURS FIRST
			BEFORE STAND'Z.	AFTER STAND'Z.		FOR ROTATABLE POOL BEFORE STAND'Z.	FOR ROTATABLE POOL AFTER STAND'Z.	FOR ROTATABLE POOL AFTER STAND'Z.	
a	104	*	6	8	0.25	20	2	2	
b	19	}	1		0.25		1		1
c	1		0.2		0.25		1		1
d	2040	*	162	213	0.25	635	41	54	
e	560	}	53		0.25		14		14
f	75		8		0.25		2		2
g	982	*	70	121	0.25	704	18	31	
h	694	}	65		0.25		16		16
i	3		0.5		0.25		1		1
j	7		1		0.25		1		1
TOTALS			366.7	342	0.25	1359	97	87	36



as indicated in Table 7. Further assume that a standardization analysis indicates the feasibility of replacing seven varieties with one of three preferred types: (a), (d), and (g) as shown. Now, if the rotatable pools are established before the decision to standardize, then the components procured to fill the pipeline for items (b), (c), (e), (f), (h) and (i) represent a possible economic loss. In the case of the ten components in Table 4, 36 unnecessary components would have been procured. If standardization action is taken first, however, then 1359 new components of the (a), (d), and (g) variety would be required to replace the nonpreferred varieties. Moreover, waiting until the standardization analysis and implementation takes place could result in not achieving significant economic benefits which would otherwise be possible through early establishment of a rotatable pool for each of the ten components.

The appropriate sequencing of standardization and rotatable pool actions depends on the order of magnitude of benefits involved, the magnitude of investment required coupled with the ability to make such an investment, and the time required to achieve implementation of either action.

#### 4. DEVELOPMENT OF ROTATABLE POOL DECISION METHODOLOGY

The rotatable pool decision methodology is needed to assist in answering two questions:

- (a) Is it economically feasible to establish rotatable pools for specific types of components?
- (b) What is the appropriate mode of repair (i.e., what level of maintenance should the rotatable pools serve, and where should repair take place)?

These questions are interdependent and can best be approached by the use of a general economic decision model.

a. A General Decision Model

The general decision model is constructed so as to allow an evaluation of the economic feasibility of adopting a remove-and-replace policy in lieu of a current policy to remove-repair-replace or repair-in-place various ships components. Such an evaluation compares the costs incurred in changing to a remove-and-replace policy with the economic benefits likely to be derived therefrom. Expressed in significant terms which affect the costs and benefits, the general decision model simply states:

If additional cost to establish and maintain a rotatable pool is less than resultant savings in remaining ownership cost plus the resultant economic value of shortened availabilities, then the rotatable pool concept is justified.

The decision model may be expressed in significant mathematical terms for each of two basic conditions, as follows:

Condition No. 1: Current policy to remove, repair and replace

$$\text{If } U\left(\frac{t}{P}\right) + h < m_1 \left[ \left(1 - \frac{m_2}{m_1}\right) (b) + \frac{qv}{wQ} \right]$$

then a rotatable pool concept is justified.

Condition No. 2: Current policy to repair-in-place

$$\text{If } U\left(\frac{t}{P}\right) + h < m_1 \left[ \left(1 - \frac{m_2}{m_1}\right) (b) + \frac{\left(g - \frac{r}{m_1}\right) (v)}{wQ} \right]$$

then a rotatable pool concept is justified.

- Where
- U = the unit cost of the component
  - t = repair or overhaul turnaround time in years
  - P = the average remaining program life in years of systems in which the components under analysis are used, or the number of years over which the analysis will be made
  - h = the additional handling costs associated with each repair or overhaul
  - $m_1$  = the unit repair cost under the current policy in terms of manhours per repair
  - $m_2$  = the unit repair cost under the proposed policy in terms of manhours per repair
  - b = the average weighted labor rate including overhead in terms of dollars per manhour
  - g = that percent or portion of the repair manhours,  $m_1$ , which can be applied to other work required during the availability so as to shorten the availability
  - v = the economic value of a ship's availability to perform its intended mission in dollars per day
  - w = the number of working hours per day
  - Q = the number of men in the available work force
  - r = the manhours per repair to remove and reinstall the component.

The derivations of the mathematical model for both conditions stated above are contained in Appendix III.

b. Application of the General Decision Model

The general decision model is applicable at any of

the three levels of maintenance - shipboard, tender or shipyard, provided that appropriate quantitative values are assigned for such constants as turnaround time ( $t$ ), weighted labor rate ( $b$ ), working hours per day ( $w$ ), and labor force ( $Q$ ). These constants are unique to the particular repair environment for which the rotatable spares concept is analyzed. The constants, remaining program life ( $P$ ) and value of ships availability ( $v$ ), are generally unique to each particular ship, although they may be determined with respect to a class of ships when appropriate. The additional handling cost ( $h$ ) is variable and while it is peculiar to the component under analysis, it also is sensitive to the location of and environment surrounding the rotatable pool.

Thus, the general decision model can be applied as an aid in evaluating different modes of repair. For example, to consider the difference in repairing or overhauling a particular type of component at a single location versus several locations, the decision model may be applied under both situations to see which results in the greatest difference in cost and benefits. Under a single point of repair policy the handling cost ( $h$ ) may increase, while the actual repair cost ( $m_1$ ) and the turnaround time ( $t$ ) decrease.

##### 5. THE NEED FOR A STATISTICAL BASE TO FEED DECISION MODELS

The economic advantages resulting from a rotatable pool concept appear much more significant in the area of shortened availabilities than in any other. However, there is a high degree of randomness as to what components control, or contribute to the control of, various availabilities. It, therefore, would be necessary to base the rotatable pool decision on the probability that the components in question would control or contribute to the control of various availabilities.

For example, a Submarine Tender currently is due in for a 5-month scheduled availability at Mare Island Shipyard. The controlling factors of the availability are the overhaul of all Main Motors, Main Generators and Motor Generators. The estimated cost to procure replacements for these major components is \$1,020,500. Planning personnel at Mare Island estimate that if these major components were available for a remove-and-replace operation, the availability could be reduced from 5 months to 3 months. If the 60 days of shortened availability was valued at \$6,000 per day, then the remove-and-replace concept would be worth \$360,000 in this one instance--not enough to justify the cost of an additional set of spares. But, if these same components were installed on other ships, and in the aggregate contributed to four or more shortened availabilities in the same order of magnitude, then an additional set of spares to facilitate a remove-and-replace policy would be justified.

If the general economic decision model were applied at each availability and the results of the "tradeoff" recorded, a statistical base could soon be established which would enable one to determine the probability that certain components would contribute to shortened availabilities by a specific amount. This would, in turn, provide the basis for making a decision regarding the application of a rotatable pool concept. Moreover, applying the general economic decision model at each scheduled availability would tend to improve the planning process and could, in some instances, result in immediate economic advantages.

Applying the general economic decision model at each availability would require little additional effort on the part of the planning personnel; the mathematical manipulations could be assigned to the computer.

### III. CONCLUSIONS AND RECOMMENDATIONS

#### 1. CONCLUSIONS

##### Rotatable Pools and Standardization

The following conclusions with respect to standardization are leveled at achieving increased standardization among components currently installed aboard in-service ships and as such are not necessarily applicable or valid with respect to achieving standardization among components during new ship construction.

Conclusion 1 - The establishment of rotatable pools and the achievement of increased component standardization are essentially two separate methods of achieving increased economy in the logistics support of Naval vessels, and both methods should be applied where appropriate.

Conclusion 2 - Achievement of increased component standardization can more directly contribute to lower remaining life cycle costs than can the establishment of rotatable pools of the same components without increased standardization; but the rotatable pool concept can make a significant contribution toward shortened availabilities which can not be achieved by standardization.

Conclusion 3 - It is more difficult to justify and achieve increased component standardization than it is to justify and establish rotatable pools of such components for the following reasons:

(1) Standardization requires more economic and technical data and requires greater technological competence.

(2) Implementation of standardization frequently requires significantly more investment in design changes,

installation rework, and acquisition of additional components.

(3) The process of standardizing is more time consuming and generally requires a longer period for payout.

Conclusion 4 - Development of interchangeability data should precede procurement of additional components necessary to establish a rotatable pool. Preference should be given to those components still in production (with repair parts being still available from the manufacturer or his distribution system), to those components having an acceptable maintenance history, and to those components having relatively high population within the fleet.

#### Methodology and Justification for Establishing Rotatable Pool Concept

Conclusion 5 - The potential benefits achievable by the implementation of the rotatable pool concept with respect to ship components are significantly large enough to warrant an immediate Navy-wide program aimed at achieving such benefits.

Conclusion 6 - The major benefit to be derived from the rotatable pool concept is shortened availabilities, although other advantages are inherent in the concept, such as better quality of repair, greater availability of repair parts at less cost, decreased component repair costs, and maintaining existing degree of standardization.

Conclusion 7 - Justification for a rotatable pool is based on investment in additional pipeline versus benefits, and an economic decision model reflecting such criteria should be developed and put into use immediately at tender and shipyard levels of maintenance. The general economic decision model developed

and presented in this report will, we believe, effectively serve this purpose.

Conclusion 8 - Selection of specific components for the rotatable pool concept should be made on the basis of their probability of contributing toward shortened availabilities and decreased unit repair cost. Such a basis of selection requires a statistical base for identifying such components because:

- (1) A rotatable pool of specific components may improve some availabilities while having no effect on others.
- (2) Specific components applicable to the rotatable pool concept are not now apparent.
- (3) Elements pacing or controlling availabilities are varied and not now documented.

## 2. RECOMMENDATIONS

Recommendation 1 - It is recommended that the Chief of Naval Material issue the necessary instructions to establish a formal "Rotatable Pool Management Program" which requires analysis of all ship components subjected to repair or overhaul at tender, restricted, and scheduled availabilities using the economic decision model presented in this report, and that the results of these analyses be used as a basis for establishing rotatable pools where appropriate.

Recommendation 2 - It is recommended further that CNM designate an appropriate focal point for implementing, coordinating, and monitoring the "Rotatable Pool Management Program."



ASSISTANT SECRETARY OF DEFENSE  
Washington, D. C.

Installations and Logistics

DATE: 19 August 1965

TASK ORDER SD-271-33  
(TASK 66-6)

1. Pursuant to Paragraph C, Article 1, of the Department of Defense Contract No. SD-271 with the Logistics Management Institute, the Institute is requested to undertake the following task:

A. TITLE: Study of Hull Mechanical/Electrical Installed Equipment Standardization for Commissioned Ships.

B. SCOPE OF WORK: This will be a study of the feasibility and advantages of achieving installed equipment standardization within classes of "in service" ships. The present methods of the planning and performance of ship overhauls will be studied in depth for the purpose of developing techniques which will attempt to standardize to the greatest practicable degree equipments within the ship class. This will necessitate the analysis of shipyard (Navy and commercial) overhaul procedures and the extent to which existing allowance list data may be used to achieve the objective.

The ultimate objective will be to improve the logistics support of commissioned ships by class as these ships go through normal overhaul.

2. SCHEDULE: A preliminary report will be submitted by 15 October, identifying the potential value of the study and defining a detailed plan of actions. A final report containing the study findings and recommendations to achieve this equipment standardization for improved support will be submitted by 15 April 1966.

/s/ Paul R. Ignatius

ACCEPTED /s/ Barry J. Shillito

DATE August 19, 1965

ASSISTANT SECRETARY OF DEFENSE  
Washington, D. C.

Installations and Logistics

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One aspect of this study will include:

1) Determination of the potential contribution of the rotatable spares concept to increased component standardization (fewer makes and models);

2) Development of a methodology for determining the feasibility of component replacement (versus repair in place) at various levels of maintenance such as shipboard, tender, and shipyard;

3) Analysis of the cost versus the benefits of setting up ashore facilities for the repair of components and the return of failed components to such facilities.

The ultimate objective is improvement in the logistics posture of the Fleet through economy in the repair and overhaul of ship components and through decreased ship-out-of-service time for maintenance.

TASK ORDER SD-271-33  
(TASK 66-6, Rev.)

2. SCHEDULE: An interim report covering supplemental points 1, 2, and 3 above, will be completed by 31 October 1966. The final report will be ready by 31 December 1966.

/s/ Paul R. Ignatius

ACCEPTED /s/ Barry J. Shillito

DATE August 19, 1966

## APPENDIX I

### A COMPONENT/EQUIPMENT STANDARDIZATION INDEX

Standardization among a group of several different varieties of a given type of component, all of which are currently in service and functionally interchangeable, may be achieved by replacing one or more of the different varieties with one of the preferred varieties. The preferred varieties may be thought of as the standard components. The standard components are often preferred over the other varieties because they are of higher quality and result in lower support cost. The components selected as standard may or may not all be currently installed and in use.<sup>1</sup> In either case some investment is generally required in order to achieve the economic benefits that are associated with standardization. The investment may include the costs associated with such things as: removal of the non-preferred component, acquisition of the standard component, and design changes for and installation of the standard component. The economic benefits to be achieved result from having fewer components and repair parts in the supply system, and from lower support costs due to the higher quality of components in use.

The investment required to achieve standardization and the economic benefits resulting from standardization vary significantly with the type of components considered and the quantity of such components currently in use. Therefore, it would seem useful to develop some yardstick by which to measure the ratio

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<sup>1</sup>If a standard component is selected which is not currently in the supply system, the cost of introducing the new component into the system and supply management costs of peculiar parts must be considered in addition to the elements of costs described in the equations contained herein.

of benefits to investment for various categories of components in order to determine where limited funds may best be invested. Such a yardstick, which we will call the "Standardization Index" (S.I.), is developed as follows:

Let  $a$  = the potential benefits in dollars achievable over some period of time (P) by reducing the variety of (N) different components which constitute a group of (e) installations;<sup>1</sup> and,

$I$  = the investment in dollars per unit required to achieve the potential benefits, (a);

so that the

$$\text{"Standardization Index" (S.I.)} = \frac{a}{Ie} \quad \text{Eq. (1)}$$

#### Potential Economic Benefits (a)

The potential economic benefits (a) may be determined by subtracting the overall net cost to the Navy incurred in installing and using a specific number of standard components from the overall net cost to the Navy incurred in retaining the same number of nonpreferred components in the system.

Let  $C_N$  = the overall net cost to the Navy of retaining (N) different varieties of a certain type of component in their current applications of (e) number of installations; and

$C_S$  = the overall net cost to the Navy of replacing (N) different varieties serving (e) number of installations; with (e) number of standard components of a single variety (s);

so that the potential economic benefits,

$$a = C_N - C_S \quad \text{Eq. (2)}$$

<sup>1</sup>The maximum number of varieties is  $N(\max) = N_t$ ; the maximum number of installations is  $e(\max.) = e_t$ ; and

$$e_t = \sum_{i=1}^{N_t} e_i$$

Now suppose that there are  $n_1, n_2, n_3 \dots n_{N_t}$  different varieties of a given type component, each of which has a population of  $e_1, e_2, e_3 \dots e_{N_t}$ , respectively. In other words, there are  $e_1$  installations of the  $n_1$  variety of a given type component in the ship or class of ships for which standardization is being considered. Now assume that all  $N_t$  different varieties of components are candidates for replacement with a preferred variety (s). Thus, the optimum number of different varieties which will be replaced is (N), and the total number of components considered for replacement is (e), where

$$e = \sum_{i=1}^N e_i \quad \text{Eq. (3)}$$

Now, let  $C_{n_i}$  = the overall net cost to the Navy of retaining the  $i^{\text{th}}$  nonpreferred variety of component in the system,

$$\text{so that } C_{n_i} = J_i Y P + e_i T_{n_i} P$$

where  $J_i$  = the number of different line items of supply which are unique to the  $i^{\text{th}}$  variety of component,

$Y$  = the supply management cost per year per line item of supply,

$P$  = the number of years over which the benefits and investment are to be appraised.<sup>1</sup>

$e_i$  = the number of installed components in the ship or class of ships considered that is of the  $n_i$  variety.

$T_{n_i}$  = the total support cost per installed component per year of the  $n_i$  variety.

---

<sup>1</sup>The future value of money has not been considered in the development of the mathematical formulæ because it is intended to compare relative rather than absolute potential benefits by component category over a constant number of years (P); hence applying a constant discount rate to benefits achievable over the same number of years would not affect relative benefits. However, if different values of (P) are used for different component categories, then the future value of money should be considered and an adjustment in the formulæ should be made to reflect the appropriate discount rates.

Now, if we assume that the average values  $\bar{J}$  and  $\bar{T}_N$  are not significantly different from  $J_i$  and  $T_{n_i}$  respectively, then the following equality may be accepted:

$$C_N = \sum_{i=1}^N C_{n_i} = \bar{J}YPN + \bar{T}_N P \sum_{i=1}^N e_i \quad \text{Eq. (4)}$$

Substituting Equation (3) into Equation (4):

$$C_N = \bar{J}YPN + \bar{T}_N Pe \quad \text{Eq. (5)}$$

Now, the overall net cost to the Navy of replacing (N) different varieties of a given type component having an aggregated number of (e) installations consist of two principal elements. First, there may be an investment cost associated with each installation; and second, there is the total support cost per installation associated with the standard variety (s).

Thus,

$$C_S = Ie + T_S Pe \quad \text{Eq. (6)}$$

where, I = the investment cost per installed component,

$T_S$  = the total support cost per installed component per year of the standard variety (s), and

e = the number of installed components of the non-preferred varieties (N) which will be replaced by the preferred variety (s).

Now, substituting Equations (5) and (6) into Equation (2):

$$a = \bar{J}YPN + e[(T_N - T_S) P - I] \quad \text{Eq. (7)}$$

Let  $(\Delta T) = \bar{T}_N - T_S$  so that

$$a = \bar{J}YPN + e[(\Delta T) P - I] \quad \text{Eq. (8)}$$

It will be noted from Equation (8) that the economic benefits (a) is a function of the number of different varieties (N) of a given type component, and the total number of installations (e) which the (N) varieties serve. The terms  $\bar{J}$ , Y, P,  $\Delta T$ , and I are each considered to have average values peculiar to the specific group of components under analysis.

Now, for any given group of components it is desirable to know what values of (e) and (N) will result in the maximum value of (a). Examining Equation (8), it will be noted that if  $(\Delta T)P > I$ , then (a) is maximum when  $e = e_t$  and  $N = N_t$ . In other words, the maximum economic benefits (a) via standardization will result in a group of ( $e_t$ ) installations consisting of ( $N_t$ ) different varieties when all installations have been replaced by preferred components, provided the average difference in unit support cost between the nonpreferred varieties and the preferred varieties over a specified period of time  $[(\Delta T)P]$  is equal to or greater than the unit investment required for replacement (I).

Referring to Equation (8) again, if  $(\Delta T)P < I$ , then the value of (a) will be maximum at some distinct values of (e) and (N). For example, suppose that we have 20 different varieties of a given type component and that we arrange the different varieties ( $n_1, n_2, \dots, n_{20}$ ) in order of the lowest number of installations per variety as shown in Table 1. Now, let A = the number of installations per distinct variety of "CID" number (Component Identification Number), and group by the lowest values of (A) as shown on Figure 1.



TABLE 1

<u>Component Variety (distinct CID Number)</u>	<u>Number of Installations per CID</u>		<u>Component Variety (Contd)</u>	<u>Number of Installations (Contd)</u>	
$n_1$	1	5	$n_{13}$	4	2
$n_2$	1		$n_{14}$	4	
$n_3$	1		$n_{15}$	5	3
$n_4$	1		$n_{16}$	5	
$n_5$	1		$n_{17}$	5	
$n_6$	2	3	$n_{18}$	6	1
$n_7$	2		$n_{19}$	8	1
$n_8$	2		$n_{20}$	10	1
$n_9$	3	4			
$n_{10}$	3				
$n_{11}$	3				
$n_{12}$	3				

Assume the following values:

$$\bar{J} = 4 \text{ line items per CID}$$

$$Y = \$100.00 \text{ per line item per year}$$

$$P = 5 \text{ years}$$

$$\Delta T = \$100.00 \text{ per installed component per year}$$

$$I = \$1150.00 \text{ per installed component}$$

In this example,  $(\Delta T)P < I$ , so we wish to determine at what values of (N) and (e) we can expect the greatest benefits (a). The benefits resulting from supply management costs ( $\bar{J}YPN$ ) increase in steps as we eliminate from the system all single application components, then double, then triple, etc., as shown in Figure 1. Added to the supply management benefits are the benefits resulting from lower support costs for each component installation replaced ( $\Delta TP_e$ ). The sum of these two economic benefits are indicated in Figure 1. Also indicated is the investment cost (Ie). It will be noted that the maximum net benefits (a) appear to occur when (e) = 23.

Figure 2 shows in greater detail how the net economic benefits vary with the number of components (e) that are replaced.

If we concentrate on removing all single application components first, then double applications, then triple applications, etc., there is a definite relationship between (e) and (N) which will result in the greatest net economic benefits (a). To demonstrate this relationship:

$$\text{Let } R = \frac{\bar{J}Y P}{\Delta TP - I} \quad \text{Eq. (9)}$$

which may be treated as a constant for any given group of similar type components.

Substituting Equation (9) into Equation (8):

$$a = (\Delta TP - I)(RN + e) \quad \text{Eq. (10)}$$

Let  $\Delta a$  = the rate of change of net benefits. Therefore,  $a = a_{(\text{max.})}$  when  $\Delta a = 0$ , provided of course that  $\Delta a$  is positive.

Since  $(\Delta TP - I)$  and R may be considered as constants and both are  $< 0$ , then  $\Delta a = (\Delta TP - I)(R\Delta N + \Delta e)$ , and  $\Delta a = 0$  when  $R\Delta N = -\Delta e$ . Now since  $\Delta TP < I$ , the net benefits

$$\text{Eq. (11)}$$

accrue primarily from removing a distinct variety ( $n_i$ ) from the supply system. Therefore, let  $\Delta N = 1$ , so that  $\Delta a = 0$  when  $\Delta e = -R$ .

The change in the population,  $\Delta e$ , is equal to the number of applications associated with the corresponding  $\Delta N$ . This is shown on Figure 1 as the column headed A. Therefore, when  $\Delta N = 1$ ,  $\Delta e = A_i$  and  $a_{(\text{max.})}$  is achieved when  $A_i = -R$ .

In the example depicted in Figures 1 and 2,  $R = -3.07$ . Therefore, since (A) must always be an integer, the maximum net economic benefits (a) will occur when we have replaced all varieties of components which have three or less component installations each, or when  $N = 12$  and  $e = 23$ .

Thus, it may be stated that: The maximum economic benefits (a) via standardization will result in a group of (e) installations consisting of (N) different varieties when the values of (N) and (e) correspond to the removal of all varieties which have component applications of a number (A) or less when (A) approaches but does not exceed the ratio of the unit supply management benefits ( $\bar{JYP}$ ) to the difference in unit support cost benefits ( $\Delta TP$ ) and unit investment (I), provided that  $\Delta TP < I$ .

Now, substituting Equation (8) into Equation (1), the "Standardization Index" may be stated as:

$$(S.I.) = \left( \frac{\bar{JYP}}{I} \frac{N}{e} \right) + \left( \frac{(\Delta T)P}{I} - 1 \right) \quad \text{Eq. (12)}$$

$$\text{Let } K_1 = \frac{\bar{JYP}}{I} \quad \text{and} \quad \text{Eq. (13)}$$

$$K_2 = \frac{(\Delta T)P}{I} - 1 \quad \text{Eq. (14)}$$

so that, for simplicity,

$$(S.I.) = K_1 \frac{N}{le} + K_2 \quad \text{Eq. (15)}$$

To determine the maximum (S.I.) for any specific group use value of (N) and (e) which prevail when (A) approaches but does not exceed  $\frac{\bar{JYP}}{\Delta TP-I}$ .

FIGURE 1

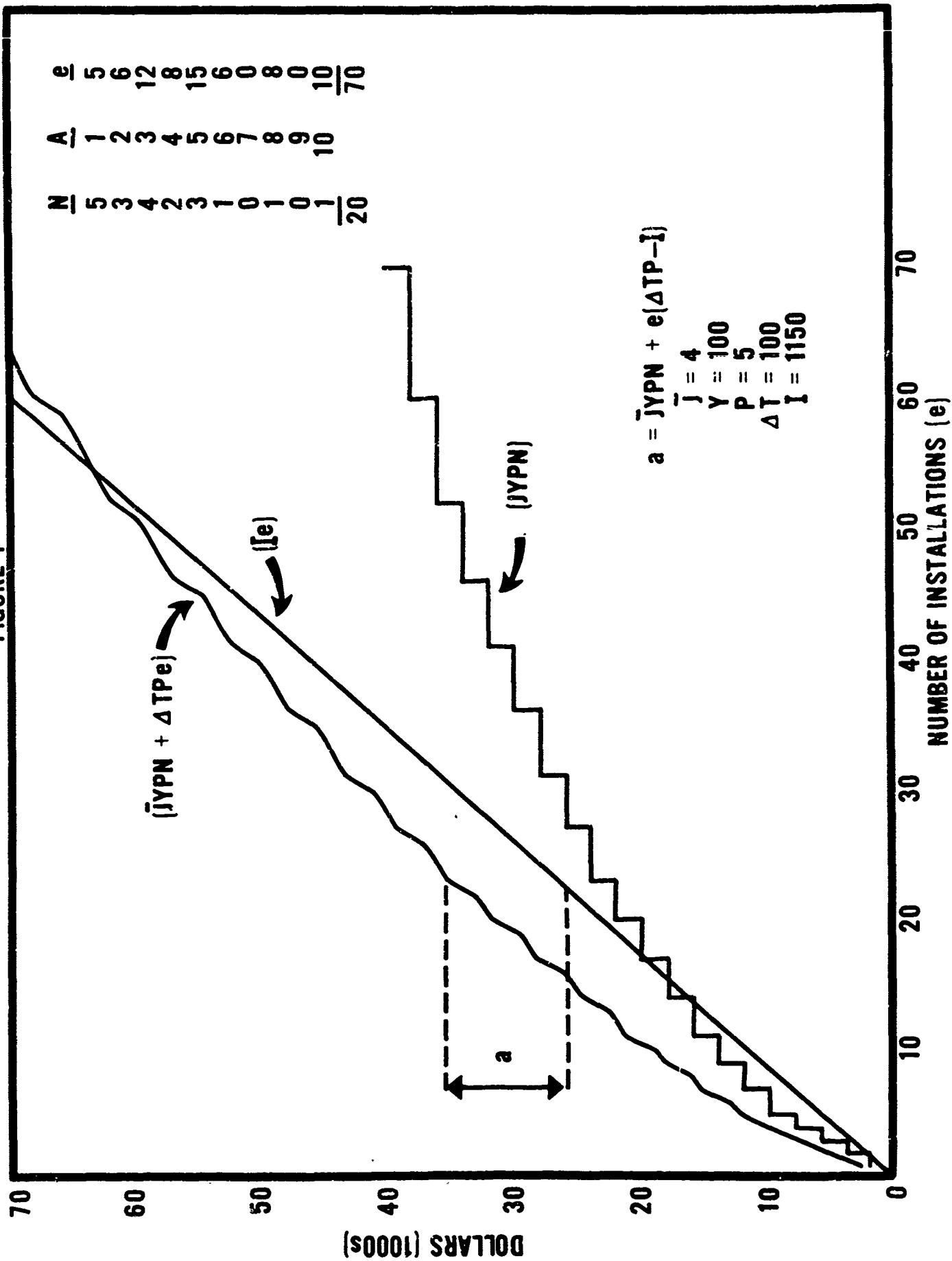
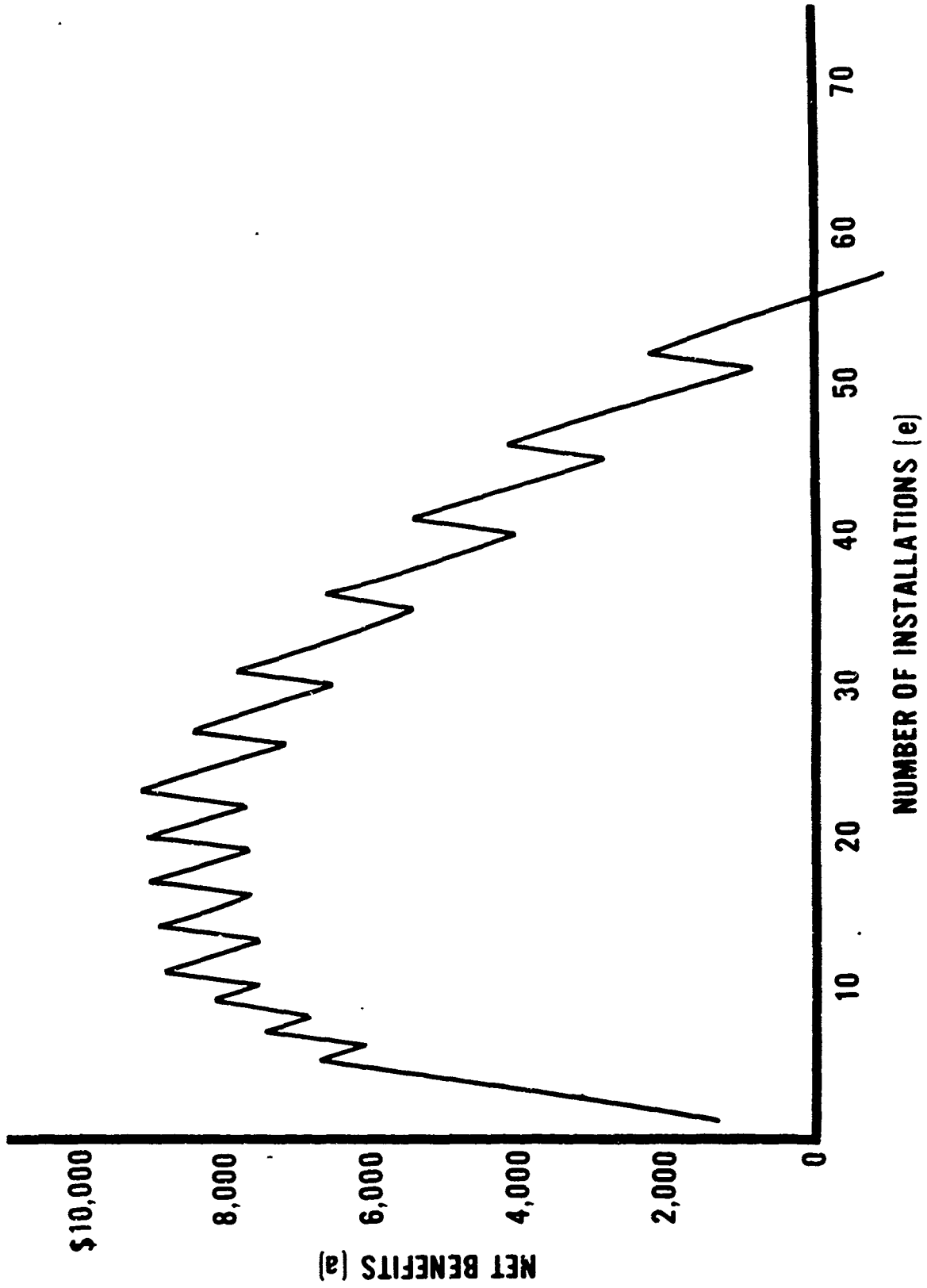


FIGURE 2



## APPENDIX II

### A MATHEMATICAL MODEL FOR DETERMINING THE OPTIMUM REPLACEMENT SCHEDULE FOR ACHIEVING C/E STANDARDIZATION

The "Standardization Index" developed in Appendix I helps to identify those areas where a potential economic advantage exists in replacing (N) different varieties of a certain type component serving (e) number of installations with a single preferred variety. We now wish to determine the most economical approach to take in replacing (N) different varieties which may or may not include all (N) varieties indicated by the Standardization Index or the optimum number to replace.<sup>1</sup> In other words, should all non-preferred components be replaced en masse, at time of scheduled overhaul, only if repair is required, etc. In order to determine the best approach, a mathematical model is developed herein which allows one to examine the potential benefits under various component replacement conditions. Naturally, the replacement schedule would be developed around those conditions which result in the greatest economic benefits.

Referring to Equation (2) in Appendix I, the potential economic benefits (a) may be expressed as:

$$a = C_N - C_S \quad \text{Eq. (1)}$$

where  $C_N$  = the overall net cost to the Navy of retaining (N) different varieties of a certain type of component in their current applications of (e) number of installations; and

---

<sup>1</sup>The subscripts contained in Appendix II refer only to those varieties considered for replacement and are not to be confused with the subscripts used in Appendix I which refer to all varieties in a functionally interchangeable grouping.

$C_S$  = the overall net cost to the Navy of replacing (N) different varieties serving (e) number of installations; with (e) number of standard components of a single variety (s).

Referring to Appendix I again, Equation (5) expresses the cost if no standardization is achieved ( $C_N$ ) in terms of its two major elements--supply management and total support.

$$C_N = \bar{J}YPN + \bar{T}_N Pe \quad \text{Eq. (2)}$$

where ( $\bar{J}YPN$ ) represents the supply management cost to the Navy to maintain (N) different component varieties in the supply system; and ( $\bar{T}_N Pe$ ) represents the total ownership costs excluding supply management associated with (e) number of component installations over a period of (P) years.

We now wish to express the two major elements of Equation (2) above in more detailed subelements so as to enable calculations of the cost  $C_N$  under different conditions of component replacement.

#### Total Support Costs ( $\bar{T}_N Pe$ )

If all (e) nonpreferred components are replaced immediately, then the total support costs associated with the nonpreferred components ( $\bar{T}_N Pe$ ) should be compared with the total support costs associated with the preferred variety ( $\bar{T}_S Pe$ ). In this case the investment required to achieve standardization will include the cost to remove and replace all nonpreferred components provided they are at the time functioning properly. On the other hand, if the replacement is not made until the nonpreferred components require repair or overhaul, and if the nonpreferred components must be removed for overhaul anyway, then the cost of component removal would be incurred whether standardization replacement took place or not. It is therefore desirable



to express ( $C_N$ ) in terms of the cost to remove, repair, and replace a certain portion of the total components ( $e$ ) over some specific duration of time. The remaining support costs, then, would be calculated over a shorter period of time than would be the case if standardization took place immediately.

Let  $e_1$  = the anticipated number of components of the total population ( $e$ ) that will require repair during some duration of time,  $P_0$ ;

$x_1$  = the average cost per component for removal;

$x_2$  = the average repair or overhaul cost per component;

$x_3$  = the average cost per component for reinstallations;

$z_1$  = repair removal factor:

where  $z_1 = 1$  if removal of component is normally required for repair, and

$z_1 = 0$  if removal of component is not normally required for repair;

$C_r$  = condemnation rate or anticipated fraction of ( $e_1$ ) components which will be uneconomical to repair and hence must be replaced; and

$U_N$  = the average unit purchase price of all nonpreferred components considered;

so that the cost of repairing or replacing ( $e_1$ ) components over an elapsed period of  $P_0$  years is:

$$e_1 \left[ z_1 (x_1 + x_3) + C(U_N - x_2) + x_2 \right] \quad \text{Eq. (3)}$$

Now, since standardization is not being considered until ( $P_0$ ) years have elapsed, the remaining support costs of nonpreferred components should be expressed as:

$$T_N e (P - P_0) \quad \text{Eq. (4)}$$

where  $\bar{T}_N$  = the average total support cost per installed component per year

$e$  = the total number of installed components considered for replacement

$P$  = the number of years over which the benefits and investment are to be appraised

$P_0$  = the anticipated number of years which will elapse before ( $e_1$ ) components require repair or overhaul.

The support costs may be stated in terms which will allow examination under various replacement conditions as the sum of Equations (3) and (4) above; or

$$\text{Support Costs} = e_1 \left[ z_1(x_1 + x_3) + C_r(U_N - x_2) + x_2 \right] + \bar{T}_N e(P - P_0)$$

Eq. (5)

#### Supply Management Costs ( $\bar{J}YPN$ )

The supply management costs as stated in Equation (5), Appendix I, may also be divided into subelements to reflect the supply management costs at various levels of supply.

Instead of considering an average number of parts peculiar ( $\bar{J}$ ) for each variety ( $n_i$ ), we will now consider the number of parts peculiar at various supply levels for the entire component population ( $e$ ).

Let  $j_1$  = the number of different line items (repair parts plus components) in the total group of ( $N$ ) different varieties which are required aboard ship and are peculiar to the ( $N$ ) varieties

$y_1$  = supply management cost aboard ship per line item per year

$q_1$  = number of ships in which ( $j_1$ ) applies

$j_2$  = the number of different line items (repair parts plus components) in the total group of (N) different varieties which are required at tender level and are peculiar to the (N) varieties.

$y_2$  = supply management costs aboard the tender per line item per year

$q_2$  = number of tenders to which ( $j_2$ ) applies

$j_3$  = the number of different line items (repair parts plus components) in the total group of (N) different varieties which are stocked at Naval supply points

$y_3$  = supply management cost at Naval supply points per line item per year

$q_3$  = number of Naval supply points to which ( $j_3$ ) applies.

so that,

$$\text{Supply Management Costs} = (q_1 j_1 y_1 + q_2 j_2 y_2 + q_3 j_3 y_3) (P - P_0) \quad \text{Eq. (6)}$$

#### Standardization Investment Costs ( $I_e$ )

The standardization investment cost may be described as follows:

$$I_e = e(x_1 + U_S + E_N - D_N) \quad \text{Eq. (7)}$$

where  $I$  = the investment cost per installed component

$e$  = the number of installed components considered in the analysis

$x_1$  = the average cost per installed component for removal

$U_S$  = the unit purchase price of the preferred component

$E_N$  = the engineering and installation costs per unit to replace a non-preferred component with a preferred variety, and

$D_N$  = the average disposal value per unit of a non-preferred component.

Cost Associated With Standardization ( $C_S$ )

Referring to Appendix I, Equation (6), the cost associated with achieving C/E standardization was expressed as:

$$C_S = Ie + T_S Pe$$

Now, since standardization replacement is not considered until  $P_0$  years have elapsed,  $(P - P_0)$  will be substituted for  $(P)$  above; and Equation (7) above will be substituted for  $(Ie)$ , so that:

$$C_S = e(x_1 + U_S + E_N - D_N) + T_S e(P - P_0) \quad \text{Eq. (8)}$$

Composite Model

Substituting Equations (5), (6), and (8) into Equation (1), the composite mathematical model for calculating standardization benefits under various replacement conditions may be stated as follows:

$$\begin{aligned}
 a = e_1 \left[ z_1(x_1+x_3) + C_r(U_N-x_2) + x_2 \right] + T_N e(P-P_0) & \text{--Support Costs for Non-Standzn.} \\
 + (q_1 j_1 y_1 + q_2 j_2 y_2 + q_3 j_3 y_3) (P - P_0) & \text{--Supply Mgt.Costs for Non-Standzn.} \\
 - e(x_1 + U_S + E_N - D_N) & \text{--Standardization Investment} \\
 - T_S e(P - P_0) & \text{--Standardization Support Costs}
 \end{aligned}$$

### APPENDIX III

#### A GENERAL ECONOMIC DECISION MODEL FOR ESTABLISHING A ROTATABLE POOL

The general economic decision model is developed on the basis that current policy is to remove-repair-replace, or repair in place, existing ships' components; and that the proposed policy of remove-replace-repair is to be economically evaluated against current policy. We therefore wish to compare the cost of changing the repair or overhaul policy with the economic advantages likely to result from such a change. The economic advantages are of two basic types--savings in Remaining Ownership Costs, and the Economic Value of Shortened Availabilities. Thus, the decision model is developed around the basic premise that if:

$$\begin{aligned} \text{Additional Costs} < & \text{Savings in Remaining Ownership Costs} \\ & + \text{Economic Value of Shortened} \\ & \text{Availabilities,} \end{aligned} \quad (1)$$

then a rotatable pool concept is justified.

#### Additional Costs

The additional costs incurred are made up of two principal elements, acquisition costs and handling costs. The first is basically a one-time cost which includes the cost of acquiring an additional number of components necessary to facilitate a remove and replace policy. This cost may be expressed as the product of "repair frequency" and the "repair turn-around time." The second, handling costs, is a re-occurring cost with each component that requires repair or overhaul and consists of additional costs incurred in packaging, packing, transportation,

and storage that would not otherwise be incurred under current policy. Thus,

Additional Costs = Acquisition Costs + Handling Costs.

Let  $U$  = the unit cost of the component,

$f$  = the repair or overhaul frequency in terms of repairs or overhauls per year; and

$t$  = repair or overhaul turn-around time in years;

So that, Acquisition Costs =  $(U) (f) (t)$ .<sup>1</sup>

Let  $h$  = the additional handling costs (including packaging, packing, transportation and storage) associated with each repair or overhaul of the component; and

$P$  = the average remaining program life in years of systems in which the components under analysis are used; or the anticipated number of years over which the rotatable spares bank will be used.

Thus, overall Handling Costs =  $(h) (f) (P)$ , and

Additional Costs =  $(U) (f) (t) + (h) (f) (P)$ . (2)

#### Savings in Remaining Ownership Costs

It has already been demonstrated that generally the only significant savings in remaining ownership costs resulting from a rotatable pool concept is a decrease in the unit repair cost brought about by batching the repair units.

Let  $m_1$  = the unit repair cost under the current policy in terms of manhours per repair,

$m_2$  = the unit repair cost under the proposed policy in terms of manhours per repair, and

---

<sup>1</sup>In estimating values entering into this and other formulae averages are being applied. This should be taken into consideration when the formulae are used.

b = the average weighted labor rate, including overhead, in terms of dollars per manhour.

Thus,

$$\text{Savings in Remaining Ownership Costs} = (m_1 - m_2) (b) (f) (P)$$

(3)

#### Economic Value of Shortened Availabilities

It has already been indicated that all, or a portion of the manhours saved by a remove and replace policy may contribute to shortened availabilities.

Let  $d_1$  = the number of days of the availability under current policy for each repair of the similar components in terms of days per repair,

$d_2$  = the number of days of the availability under proposed policy of remove and replace for each repair in terms of days per repair, and

v = the economic value of a ship's availability to perform its intended mission in dollars per day (see page 34).

So that,

Economic Value of Shortened Availability =

$$(d_1 - d_2) (v) (f) (P)$$

Now, let r = the manhours per repair to remove and reinstall the component

So that, for components which are normally removed for repair:

$$d_1 = \frac{r + m_1}{wQ} \quad \text{and}$$

$$d_2 = \frac{r + (i - g)m_1}{wQ}$$

where w = the number of working hours per day, and

Q = the number of men in the available work force,  
and

$g$  = that percent or portion of the repair manhours, ( $m_1$ ), which can be applied to other work required during the availability so as to shorten the availability.

Thus, for components which are normally removed for repair:

$$(d_1 - d_2) = \frac{r + m_1}{wQ} - \frac{r + (1 - g)m_1}{wQ}, \text{ or}$$

simplifying,  $(d_1 - d_2) = \frac{gm_1}{wQ}$ , and,

Economic Value of Shortened Availability =

$$\left( \frac{gm_1}{wQ} \right) (v) (f) (P) \quad (4a)$$

Now, for components which are normally repaired in place:

$$d_1 = \frac{m_1}{wQ} \quad \text{and} \quad d_2 = \frac{r + (1 - g)m_1}{wQ}$$

So that,  $(d_1 - d_2) = \frac{gm_1 - r}{wQ}$  and

Economic Value of Shortened Availability =

$$\left( \frac{gm_1 - r}{wQ} \right) (v) (f) (P) \quad (4b)$$

### Composite Model

The general decision model states that a rotatable pool concept is justified if inequality (1) is satisfied. Thus, using (2), (3), and (4a) in (1) we have the conditions under which a rotatable pool concept is justified for components which are normally removed for repair, namely if:



$$(U) (f) (t) + (h) (f) (P) < (m_1 - m_2) (b) (f) (P) + \frac{gm_1}{wQ} (v) (f) (P)$$

$$U \left( \frac{t}{P} \right) + h < (m_1 - m_2) (b) + \left( \frac{gm_1}{wQ} \right) (v)$$

$$U \left( \frac{t}{P} \right) + h < m_1 \left[ \left( 1 - \frac{m_2}{m_1} \right) (b) + \frac{gv}{wQ} \right]$$

where  $U$  = the unit cost of the component

$t$  = repair or overhaul turn-around time in years

$P$  = the average remaining program life in years of systems in which the components under analysis are used; or the anticipated number of years over which the rotatable spares bank will be used

$h$  = the additional handling costs (including packaging, packing, transportation and storage) associated with each repair or overhaul of the component

$m_1$  = the unit repair cost under the current policy in terms of manhours per repair

$m_2$  = the unit repair cost under the proposed policy in terms of manhours per repair

$b$  = the average weighted labor rate including overhead in terms of dollars per manhour

$g$  = that percent or portion of the repair manhours,  $m_1$ , which can be applied to other work required during the availability so as to shorten the availability

$v$  = the economic value of a ship's availability to perform its intended mission in dollars per day

$w$  = the number of working hours per day

$Q$  = the number of men in the available work force

$r$  = the manhours per repair to remove and reinstall the component

The decision model, therefore, may be stated as follows  
for components that are normally removed for repair  
or overhaul:

$$\text{If } U \left( \frac{t}{P} \right) + h < m_1 \left[ \left( 1 - \frac{m_2}{m_1} \right) (b) + \frac{gv}{wQ} \right],$$

then a Rotatable Pool Concept is justified.

In like manner, replacing (4a) by (4b) it is determined  
that for components that are normally repaired in place  
the decision model would state:

$$\text{If } U \left( \frac{t}{P} \right) + h < m_1 \left[ \left( 1 - \frac{m_2}{m_1} \right) (b) + \frac{\left( g - \frac{r}{m_1} \right) (v)}{wQ} \right],$$

then a Rotatable Pool Concept is justified.

## APPENDIX IV

### A STANDARDIZATION/ROTATABLE POOL SEQUENCING DECISION MODEL

This decision model is developed as a method for determining whether a group of similar type components, each of which has been justified as applicable to the rotatable pool concept, should be reduced to a minimum variety through standardization before making an investment in additional components to fill the rotatable pools. Thus, there are two alternative approaches to be evaluated against one another. Figure 1 illustrates the first approach, which is to establish rotatable pools for each type of component immediately and then to reduce the variety of components through standardization subsequently. Figure 2 illustrates the second approach, which is to defer establishment of the rotatable pools until a greater degree of standardization has been achieved and hence decrease the variety of additional types of components required for the rotatable pools.

Referring to Figure 1, let:

$I_1$  = the investment in rotatable pools for a group of similar components without achieving increased standardization among the group

$R$  = the average annual net benefits (exclusive of initial investment,  $I_1$ ) resulting from the application of rotatable pools for the entire group of similar components, and

$P_r$  = the number of years required for the initial investment in rotatable pools,  $I_1$ , to equal the economic savings resulting from the use of rotatable pools;

FIGURE 1

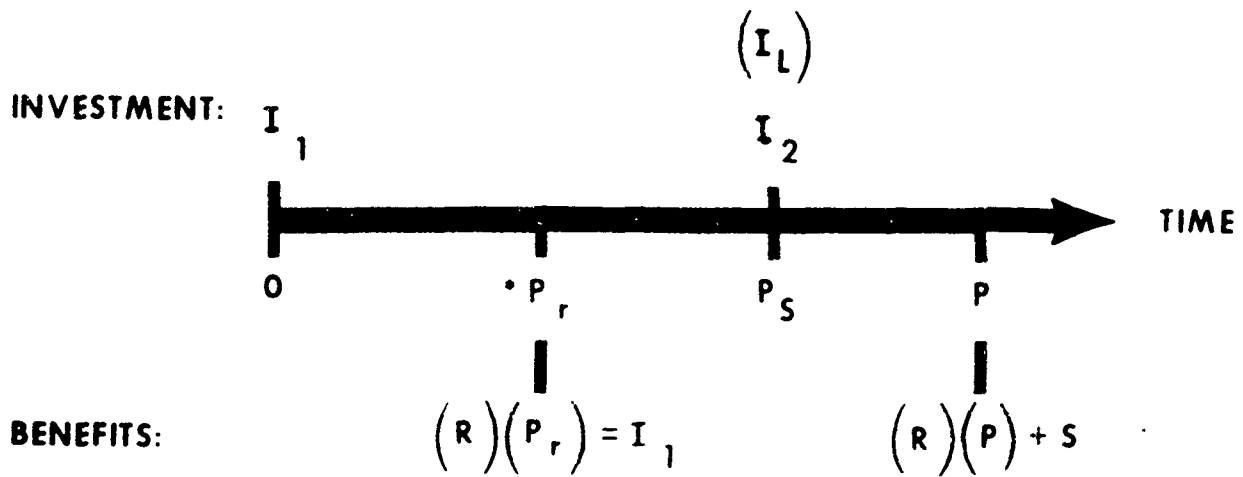
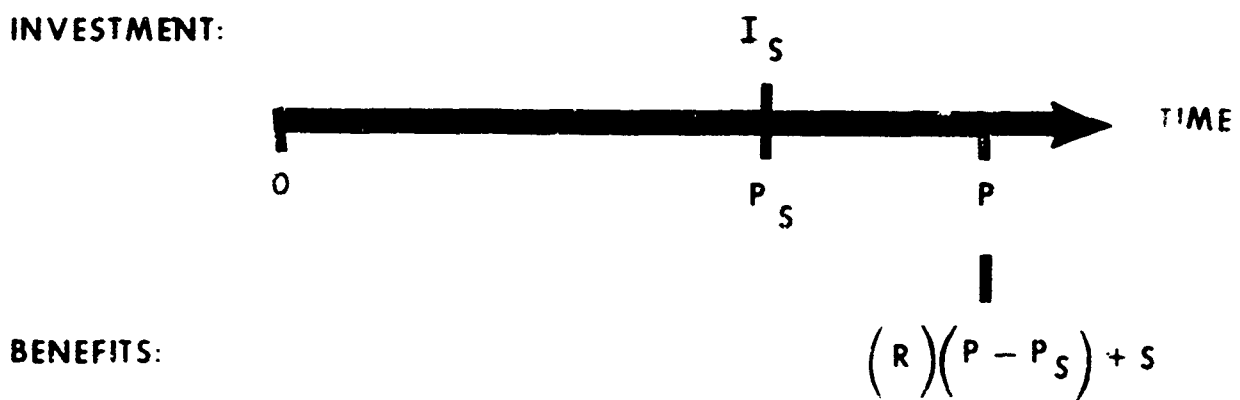


FIGURE 2



\*  $P_r$  COULD, OF COURSE, FALL TO THE RIGHT OF  $P_s$

So that,  $I_1 = (R)(P_r)$

Now, at some point during the remaining program life, (P), assume that increased standardization is achieved among the original group of similar components, and it is desirable to continue the rotatable pool concept with respect to the decreased variety of components. This means that an additional number of components of the standard variety will be required to fill the rotatable pools, while the non-standard type components, initially procured for the rotatable pools are no longer required.

Let  $I_2$  = the additional investment in rotatable pools of the standard variety required after increased standardization has occurred

$I_L$  = that portion of the initial investment in rotatable pools ( $I_1$ ) which was made to procure components of the non-standard variety

$P_s$  = the anticipated number of years required to achieve increased standardization among the original group of components

$P$  = the anticipated number of years over which the rotatable pools will be used

$S$  = the net benefits achievable through standardization exclusive of those similar type benefits which are a direct result of the rotatable pool concept, and

$I_s$  = the investment in rotatable pools after standardization has been achieved

Now, in order to select the best approach, we will compare the net benefits achievable if rotatable pools are established prior to standardization (Figure 1) with the net benefits achievable if the rotatable pools are established after increased standardization has occurred (Figure 2).

Let  $B_r$  = the net benefits achievable from both the rotatable pool concept and standardization if rotatable pools are established first, standardization is achieved subsequently, and rotatable pools for the standard components are continued in use (Figure 1), and

$B_s$  = the net benefits achievable from both the rotatable pool concept and standardization if standardization is achieved prior to establishing any rotatable pools;

so that,

$$B_r = (R)(P) + S - I_1 - I_2, \text{ and}$$

$$B_s = (R)(P - P_s) + S - I_s$$

Thus, the decision to establish rotatable pools prior to achieving standardization will be justified if:

$$B_s < B_r; \text{ or, upon substitution, if}$$

$$(R)(P - P_s) + S - I_s < (R)(P) + S - I_1 - I_2$$

Now, the investment in rotatable pools for standard components,  $I_s$ , is made at one point in the second approach (Figure 2), while in the first approach (Figure 1), the same investment is made at two points and includes all of  $I_2$  and  $I_1 - I_L$ . Any difference in  $I_s$  and the sum of  $I_2 + I_1 - I_L$  can generally be considered negligible. Thus, it may be assumed that:

$$I_s = I_2 + I_1 - I_L$$

Substituting for  $I_2$  in the decision model, the decision to establish rotatable pools prior to achieving standardization will be justified if:

$$(R)(P - P_s) + S - I_s < (R)(P) + S - I_1 - I_s + I_1 - I_L$$

or if:

$$I_L < (R)(P_s).$$

But, referring to Figure 1, it will be noted that:

$$R = \frac{I_1}{P_r}$$

Now,  $I_1$  represents the initial investment or acquisition costs of the rotatable pools required and is equal to the product of  $(U)(f)(t)$  -- see page 2 of Appendix III.

Referring again to Appendix III, page 6, and the economic decision model, it will be noted that the initial investment in rotatable pools is equal to the economic benefits derived therefrom when  $P = P_r$ , so that if  $P_r$  is substituted for  $P$  in the general economic decision model, then:

$$U \frac{t}{P_r} + h = m_1 \left[ \left( 1 - \frac{m_2}{m_1} \right) b + \frac{qv}{wQ} \right]$$

For simplicity in the derivation, let

$$X = m_1 \left[ \left( 1 - \frac{m_2}{m_1} \right) b + \frac{qv}{wQ} \right] - h$$

so that the expression may be written:

$$U \frac{t}{P_r} = X, \quad \text{or}$$

$$P_r = \frac{Ut}{X}$$

Now, substituting for  $I_1$  and  $P_r$ :

$$R = \frac{Uft}{\frac{Ut}{X}} = fX$$

Now, substituting for R and then for X in the Standardization/Rotatable Pool Sequencing decision model, we find that:

The decision to establish rotatable pools prior to achieving standardization for a group of components that are normally removed for repair will be justified when:

$$\frac{L}{P_s} < \left( m_1 \left[ \left( 1 - \frac{m_2}{m_1} \right) b + \frac{gv}{wQ} \right] - h \right) \quad (f)$$

Following the same procedure for components that are normally repaired in place:

The decision to establish rotatable pools prior to achieving standardization for a group of components that are normally repaired in place will be justified when:

$$\frac{I_r}{P_s} < \left( m_1 \left[ \left( 1 - \frac{m_2}{m_1} \right) b + \frac{\left( g - \frac{r}{m_1} \right) v}{wQ} \right] - h \right) \quad (f)$$