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CRITERIA FOR REPAIR VS. DISCARD DECISIONS
TASK 65-15

Technical Report

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June 1982

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CRITERIA FOR
REPAIR vs. DISCARD
DECISIONS

Task 65-15

May, 1966

LOGISTICS MANAGEMENT INSTITUTE
4900 Massachusetts Avenue, N. W.
Washington, D. C.

CRITERIA FOR
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FOREWORD

Decisions to repair or discard items of military equipment when such items fail or malfunction are major support decisions which should be considered prior to the time of failure. This study develops procedural guidelines and decision criteria which will improve these decision processes. The study recognizes that various other support decisions affect the economics of the repair/discard decision, and, conversely, that the decision to repair or discard affects other related support decisions. The study further recognizes that the decision to repair or discard can have a significant impact on operational readiness postures to sustain military missions. Thus, the objective sought in the development of decision guidelines for repair/discard is maximum military effectiveness or operational readiness without sacrificing economic balance among major facets of logistics support. "Integrated decision analysis," a method for achieving this objective, is presented in the report. Further development and application of this technique for a number of interrelated support functions can result in a major contribution to the effective and efficient operation of the military departments.

SUMMARY

Recognizing that the life cycle costs associated with military equipments are significantly influenced by the decisions to repair or discard such equipments or subassemblies thereof, LMI conducted a reconnaissance study in the spring of 1964 to determine the feasibility of launching a full-scale study aimed at improving the methodology for arriving at a repair or discard decision. This task was subsequently initiated early in 1965 with the objective of developing appropriate economic criteria and guidelines for use by designers of military equipment and Government decision makers in reaching repair or discard decisions.

A review of many related studies prepared over the last five to ten years, most of which included economic decision criteria, led us to several early conclusions which contributed to the formulation of our study approach. First, and perhaps most important, was recognition of the fact that the quantitative values of most decision criteria are dependent on the results of a variety of design and support decisions other than the repair or discard decision. Second, the repair/discard decision is directly or indirectly made at several major points in the life cycle of military equipments, and effective discipline over the decision process at each point requires recognition of the behavior of pertinent economic criteria at each occasion for making the decision. Conceptually, the potential economic advantage resulting from the correct repair/discard decision is greater the earlier in the life cycle the decision is made; but practically, the ability

to accurately quantify the decision criteria is more difficult. Thus, it was concluded that the study should encompass all major points of decision, and the decision guidelines developed should be compatible at all decision points and provide a basis for trade-off as regards making the decision or deferring it to a point of greater vantage. Finally, application of comprehensive and detailed decision criteria to all items or assemblies for the purpose of making a repair/discard decision is not feasible and should be applied only in those cases where an effective screening process has indicated a significant economic differential between the repair or discard choice.

Based on the early conclusions, the study was directed toward four primary objectives:

- Identification and analysis of the points in the life cycle where the repair/discard decision should be considered.
- Identification and analysis of major economic criteria.
- Development of screening rules for guiding those who make the decisions.
- Identification and analysis of other decisions affecting the choice of repair or discard.

The study identified five major points in the life cycle where the repair/discard decision might logically be considered. These are:

- Development of Design Specification--(i.e., development of design procurement specifications which may include specific requirements for items to be designed as a repairable or as a discard).

- Initial Design or Item Selection--(i.e., the actual design or selection of items which are either capable of being repaired or specifically designed as discards).
- Initial Source Coding (for Provisioning)--(i.e., designating the item as a repairable or as a non-repairable, generally at the time of initial provisioning).
- Coding/Design Review--(i.e., a review of the repairability code or the design configuration any time after the item has been entered into the military supply system).
- Repair Action--(i.e., a decision to repair or discard an individual item at the time it has failed or is malfunctioning).

A mathematical decision model was developed which identified specific criteria as applicable to ten major cost elements:

- Design Cost
- Initial End Item Procurement Cost
- Replacement Cost
- Preventive Maintenance and Operational Cost
- Corrective Maintenance Cost
- Supply Cost
- Cost of Specialized Corrective Maintenance, Tools and Test Equipment
- Documentation Cost
- Training Cost
- Disposal Value

To impute all of these elements in an exhaustive economic analysis for all hardware items is not practical. Elaborate

analysis is appropriate only if an effective screening process has indicated a significant economic differential between the repair and discard choices. Screening rules have been developed that can be applied rapidly and at nominal cost. They result in one of the following:

1. An immediate repair or discard choice.
2. Exhaustive economic analysis prior to a decision.
3. Deferring the decision to the next point in the life cycle where it can be made.

There are two general screening rules applicable at all decision points:

- Assume that the item will be repaired until a discard choice has been justified.
- Direct the analysis initially toward the highest level of assembly. Then if the decision has been made to repair this item, direct the analysis to the next lower level.

Each decision point requires unique screening rules commensurate with the ability to quantify sensitive decision criteria at that point in the life cycle.

There are numerous other decisions that can significantly influence the repair/discard choice. Some related decisions may have already been made and hence cannot be controlled by persons responsible for the repair/discard decision. Such decisions may result in constraints over the repair/discard choice. Other related decisions may not have been made or are susceptible to change at the time the repair/discard decision is considered. These decisions may represent decision

prerogatives available for consideration by persons responsible for the repair/discard decision.

Some of the related decisions are:

- Reliability versus Unit Cost
- Standardization versus Non-Standardization
- Type of Procurement and Volume Purchased
- Contractor versus Military Maintenance
- Preventive versus Corrective Maintenance
- Level of Maintenance
- Centralized versus De-Centralized Maintenance

The study highlights the close relationship among these decisions. Optimum support strategy cannot be achieved unless these issues are resolved in concert; hence integrated decision analysis is necessary for a proper repair/discard choice.

The repair/discard decision process consists of four major steps:

1. Determine the constraints over the repair/discard decision.
2. Determine the decision prerogatives which should be exercised.
3. Apply screening rules before subjecting items to an exhaustive economic analysis.
4. Make the repair/discard decision (if it has not already been made) by conducting an exhaustive economic analysis exercising appropriate related decision prerogatives through integrated decision analysis to obtain an optimum balance among support economy, military effectiveness, and operational readiness.

The study conclusions are:

1. Items entering or entered in the military supply system should be subjected to a repair/discard decision analysis using a screening process which rapidly and at nominal cost either indicates the decision or defers the decision to a point of greater vantage by initially favoring repair, and calls for an exhaustive economic analysis only when significant benefit appears likely.
2. To achieve a more optimum balance of economic support without sacrificing military effectiveness or operational readiness, appropriate repair/discard decisions must be integrated with certain other related decisions.

Based on these conclusions, the following recommendations are made:

1. It is recommended that uniform procedures for making repair/discard decisions be established by System Program Managers, Inventory Managers and Maintenance Depot Managers using the LMI report as a guide.
2. It is recommended that the application of repair/discard decision procedures, including consideration for related decisions, be required of contractors in the design and development of future major programs and that the decision network and management plan for making such decisions be made a requirement in Contract Definition.
3. It is recommended that appropriate steps be taken to encourage DoD contractors with current Development or Production contracts to utilize the guidelines for making repair/discard decisions presented in this report as a means of broadening the scope of their Value Engineering Programs.

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I. INTRODUCTION

BACKGROUND

Examining the many facets of military logistics often necessitates identifying and describing both qualitatively and quantitatively the major elements of cost associated with the development, operation, and support of military weapon systems. In the interest of minimizing duplication of effort, and assuring that full consideration be given to downstream logistics costs where appropriate, LMI undertook a task late in 1963 directed toward examining " . . . the area of life cycle (total) costing as it relates to the economics of competitive procurement"

It quickly became apparent in examining "life cycle costs" that the existence of many of the cost elements associated with a specific piece of hardware could be tied directly to a specific identifiable decision. It was recognized that some of these decisions have such significant impact on acquisition, operational and support costs so as to influence appreciably, in many cases, the order of magnitude of such costs.

The decision to repair or to discard an item of equipment when that item failed conspicuously stood out as one such decision which could appreciably influence the nature and magnitude of life cycle costs. Thus, it was decided that an independent analysis of the methodology for arriving at a repair or discard decision might be warranted. It was on this basis that LMI began to examine the repair/discard decision under Task 4C-4-- a reconnaissance effort.

The reconnaissance effort was directed toward a brief but broad review of the major points for making a repair/discard decision, the existing methods or criteria employed in the decision process, and the effects of such decisions on the logistics support posture--all with a view toward determining the feasibility of launching a full-scale study. The results of the reconnaissance effort suggested the need for additional study and, thus, Project 65-15 was initiated.

It is useful to contemplate the background leading to the initiation of this task for several reasons. First, it helps to provide perspective in viewing the repair/discard decision as a segment of the total weapon system support picture. Second, it seems to suggest the necessity for analyzing the repair/discard decision in a manner that allows a tie-back into the concern out of which this specific decision grew--namely, the impact on life cycle costs. Finally, it provides a basis for better appreciating the complexities of the problem--a condition which compels the type of approach developed in this report.

OBJECTIVES AND SCOPE OF THE STUDY

The objectives of this task were to develop appropriate economic criteria and guidelines for use by designers of military equipment and Government decision makers in reaching decisions whether items or assemblies should be repaired or discarded.

The key word in the statement of objectives is "appropriate." This connotes feasibility of application, availability of data, and sensitivity in achieving the ultimate purpose of such guidelines or economic criteria. Thus, it becomes important to have

a clear understanding of the ultimate purpose toward which this task is directed. The purpose then, of developing appropriate guidelines and criteria is to provide a sound basis for making repair/discard decisions so that such decisions will contribute to the greatest extent possible toward achieving an optimum economic balance among the various major facets of logistics support without sacrificing military effectiveness or operational readiness.

Pursuant to the objectives and purpose stated above, the scope of the study was established by four early decisions. First, it was decided to examine all major points where the repair/discard decision might logically be made or reviewed regardless of whether this type of decision was currently being given consideration or not. Second, non-economic factors which affect the repair/discard decision or might result from such a decision with an impact on military effectiveness or operational readiness would not be restricted from consideration. Third, consideration would be given to the impact of a repair/discard decision on other related technological or support decisions; and conversely, to the impact that other such decisions might have on the question of repair versus discard. Finally, consideration would be given to the necessary requirements for successfully applying whatever guidelines or criteria that might be developed.

The study approach consisted of a review and analysis of related studies, synthesis and analysis of an ideal repair/discard decision model, a number of selected field investigations, and the selection and analysis of one major case.

II. FINDINGS AND ANALYSIS

PROBLEM PERSPECTIVE

Definition of the Problem

During the reconnaissance study, it became apparent that the subject of whether to repair or discard at failure an item of military equipment was not one which had been neglected. Many recent studies¹ were identified that examined either directly or indirectly the repair or discard issue. With such attention being given to the subject over the past five to ten years, the question arises as to why repair or discard decisions are still suspect of being far from a point of optimization. Pursuit of the answer to this question contributed a great deal toward formulating the study approach.

Most of the studies reviewed included the development of mathematical decision models--many of which were extremely detailed and explicit. The economic criteria included in the various mathematical decision models were generally compatible and any differences could usually be attributed to the differences in scope of the individual studies or the environments in which the studies took place. In conclusion, we could find no justifiable reason why application of the economic criteria identified in these models would not provide the basis for making correct repair/discard decisions, provided that the quantitative values applied were accurate representations of the cost elements or equipment characteristics.

¹A bibliography of the related studies reviewed by LMI in this task is included as Appendix I.

Application of the economic criteria developed in various studies reviewed by LMI was analyzed with regard to the methods and results of quantifying the criteria under realistic user environments. In other words, the analysis attempted to evaluate the effectiveness of the decision criteria when quantified and used to make repair/discard decisions at the time such decisions might logically be considered. This analysis led to several early conclusions in our study. First, certain decision criteria when quantified on a "standard" cost basis often reflect an erroneous picture of associated costs due to non-uniformity in the interpretation or definition of such criteria. For example, applying a "standard" cost to "enter an item into the supply catalog" is meaningful only when the functions associated with such entry are consistent.

Second, quantified values of certain decision criteria depend on the number of similar units of equipment that may be subjected to the same operation simultaneously. For example, "processing a repair work order" for a single unit of equipment may cost \$2.00, but if repair work orders are processed for lots of 100 units in a single operation, the pro rated cost per unit may be only \$0.05.

Finally, and perhaps the most important of these early conclusions, the quantitative values of most decision criteria are dependent on the results of a variety of design and support decisions other than the repair or discard decision. In brief, the economics associated with a repair or discard choice are critically affected by the results of other related decisions. Moreover, many of these related decisions are subject to change and do, in fact, often change during the service life of a particular category of equipment, and hence, the economic

advantage associated with a repair or discard choice may be reversed with regard to that particular category of equipment. For example, we observed cases where the unit cost of a particular item varied by over 300% depending on procurement decisions regarding type of contract and number of units procured.

Further analysis regarding the practical application of previously developed repair/discard decision models indicated the necessity to apply relatively simple decision criteria as a screening process before considering detailed economic analyses. It was found that those decision models which included comprehensive coverage of cost elements associated with repair or discard and which sub-divided these elements into very detailed criteria were not feasible for broad application. There are three principal reasons why it is not feasible to apply such decision models in all cases where repair/discard decisions are required. First, such detailed analyses are costly and the economic advantage resulting from the correct repair/discard choice with regard to many items or assemblies is insignificant. Second, most current data systems or accounting systems do not provide an available means of quantifying detailed criteria that are of an operational nature. Third, time does not permit the analyst under actual environmental conditions to make a detailed analysis of all items or assemblies under his cognizance.

In summation, the decision to repair or discard an item or assembly is basically an economic decision where the associated economic criteria may be determined, influenced or over-ruled by other support, design or military planning decisions.

Direction of Study Approach

The primary objective of this study is to develop improved repair/discard decision guidelines and criteria which will result in greater economy to the Government and increased military effectiveness and operational readiness. In pursuit of this objective, it is necessary to approach the study with a view toward practical application and with recognition for the influences that other related decisions may have on the economics of a repair or discard choice. This study effort was, therefore, directed toward seeking answers to four principal questions.

1. At what points in the life cycle of military equipments should a repair/discard decision be considered?
2. What are the major economic criteria in terms capable of broad application, and how do the criteria bear on the decision at each major point of consideration?
3. How can the economic criteria be reduced to a relatively simple set of screening rules in order to avoid costly analysis when the potential savings are small?
4. What are the more significant related decisions and how can we deal with the interfaces between these decisions and the repair/discard decision?

Following a brief discussion of Problem Environment and Achievable Benefits, the report addresses in turn the above four questions and subsequently presents our proposed guidelines and criteria for reaching repair/discard decisions.

Problem Environment

Although the repair or discard issue may be directed toward any item of equipment used by or for the Military

Departments, we are primarily concerned with those items which enter the military supply system through the development and acquisition phases of major programs for two reasons. First, many studies have indicated that the vast majority of items in the military supply system--perhaps as high as 80-85%--enter via the major weapon system or program route. Second, the magnitude of parts and equipments involved, and the complexity of systems acquisition and support make the appropriate repair or discard choice economically significant though something less than apparent, and thus, this area provides a fruitful field for improvement. This study, therefore, has directed primary attention toward those items or subassemblies which are designed or selected by prime contractors, subcontractors, and vendors associated with major programs.

Achievable Benefits

The rewards of selecting the correct repair or discard choice are both economic and non-economic. The latter may be reflected as an increased degree of operational readiness in that the repair or discard choice may affect such things as system mobility, range and depth of support pipeline, and type and number of support skills required.

The economic benefits achievable through appropriate repair/discard choices are derived from all major elements of life cycle costs. The correct decision is not generally apparent, nor can it always be accurately determined on the basis of past experience. The only sure way of determining the economic advantage of repair versus discard is to make an exhaustive economic analysis. Our investigations indicated, however, that generally the current approach leaned more toward judgment and past experience for determining the repair/discard choice.

There are many cases where the repair or discard choice is unquestionably clear based on judgment and past experience. The area of uncertainty, however, was found to be very broad including items or assemblies where the unit costs ranged from \$5 to \$4,000.

We were unable to establish, within the area of uncertainty, a statistically valid estimate of potential cost reduction achievable through improved repair/discard choices. However, Table 1 will illustrate the differences in repair and discard life support costs with respect to a sample of ten actual equipments.

TABLE 1

EXAMPLES OF DIFFERENCE IN REPAIR AND DISCARD
SUPPORT COSTS FOR ANTICIPATED PROGRAM LIFE (8 Years)

Unit Cost of Item	Repair Cost	Discard Cost	Difference in Repair & Discard Cost	Support Costs Under \$100 Rule-of-Thumb	Support Costs Resulting From Decision Based on Econ. Analysis
\$ 6.25	\$ 2,395	\$ 5,762	\$ 3,367	\$ 5,762	\$ 2,395
14.	6,957	53,476	46,519	53,476	6,957
40	161,978	476,848	314,870	476,848	161,978
260	86,189	134,698	48,509	86,189	86,189
300	12,906	48,734	35,828	12,906	12,906
350	735,077	1,265,230	530,153	735,077	735,077
430	115,008	6,961	108,047	115,008	6,961
710	1,499,696	3,702,035	2,202,339	1,499,696	1,499,696
1,050	257,788	53,716	204,072	257,788	53,716
3,520	31,183	10,557	20,626	31,183	10,557
	\$2,909,177	\$5,758,017	\$3,514,330	\$3,273,933	\$2,576,432

Each item or subassembly listed in Table 1 was subjected to an exhaustive economic analysis under both a repair and discard choice because the most economical choice was not

clear. These are actual cases taken from the files of a current major weapon system.

There have been recent tendencies to use a unit cost of \$100 as a general dividing line for repair or discard decisions. That is, items that cost over \$100 per unit would tend to be considered reparable and those under \$100 per unit would tend to be considered discard. If such a rule-of-thumb had been applied with respect to the items in Table 1 in lieu of an exhaustive economic analysis, the support costs for the items listed would be \$3,273,933. Basing the decisions on the results of the economic analyses, however, would have resulted in support costs of \$2,576,432 or a cost reduction of 21.3%.

If we conservatively assume that only 10% of the items or subassemblies entering the military supply system through major programs fall into the category of uncertainty regarding repair or discard choices, and that these 10% represent an equal prorated share of the annual support dollars (approximated at \$20 billion), then some \$2 billion annually is involved with respect to items where the decision to repair or discard is not clear. If we further assume that without any improvement in the repair/discard decision process, we do no better or no worse than indicated in Table 1 by tending to follow the \$100 rule-of-thumb, then there would appear to be a potential cost reduction possible through improved methods of \$426 million per year (21.3% of \$2 billion).

We do not suggest that the above analysis provides a statistically valid basis for estimating gross savings which are possible through improving the repair/discard decision process. We do, however, believe that such analyses help to conservatively place the order of magnitude of possible savings in terms of multi-millions of dollars.

MAJOR POINTS OF DECISION

There would appear to be five major points in the life cycle where the repair/discard decision process might logically take place. These are:

- Development of Design Specifications
- Initial Design or Item Selection
- Initial Source Coding (for Provisioning)
- Coding/Design Review
- Repair Action

Figure 1, "Repair vs. Discard Decision Points," will aid in illustrating the interactions of the decisions which might be made at these various points.

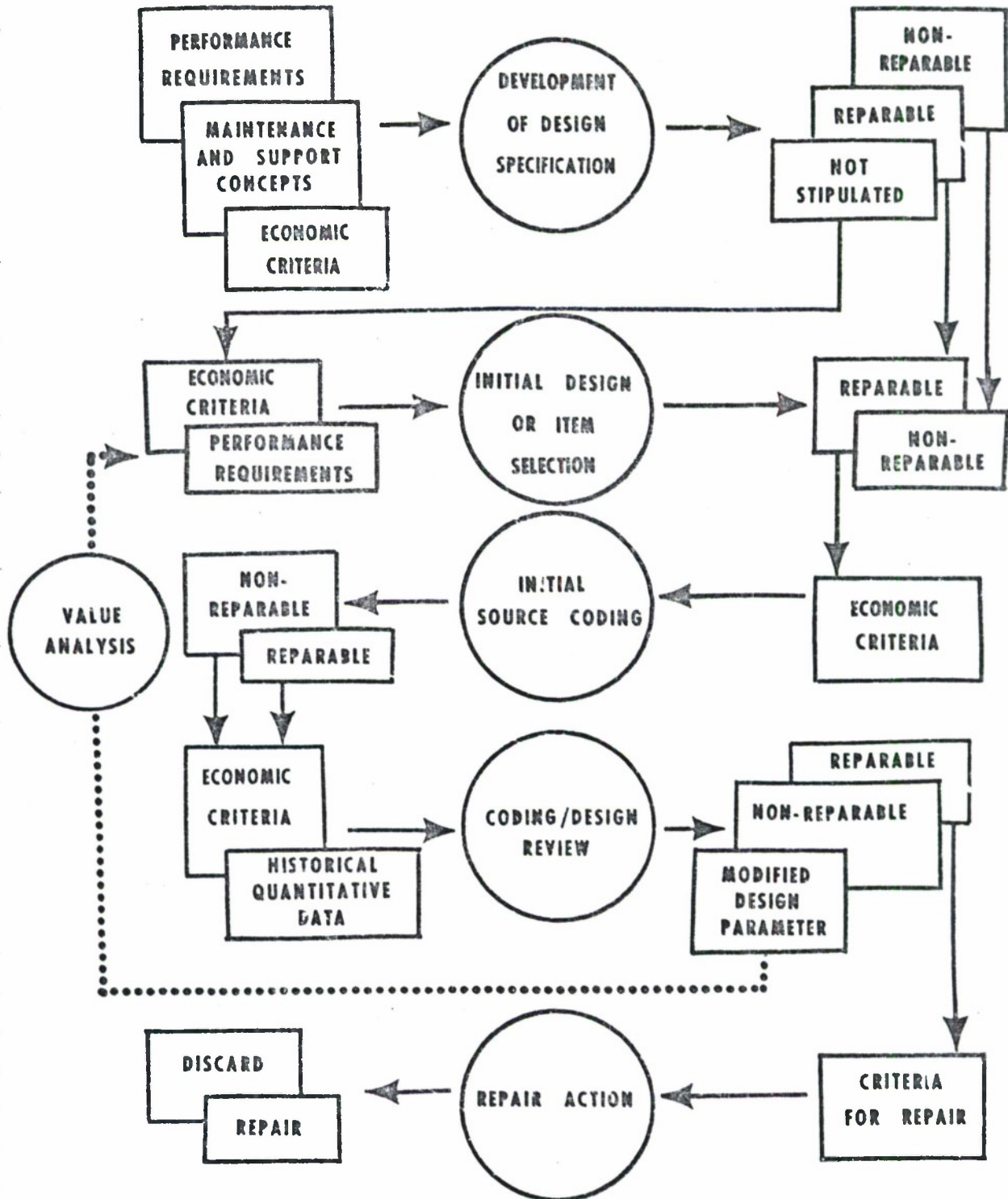
Development of Design Specifications

For items or assemblies which are designed specifically for military use, the first major decision point where repair/discard considerations might be made would occur during the development of design specifications.

A repair/discard decision at this point would result in stipulating as a requirement in the design specification that the item be designed either as a repairable or as a non-repairable. If no decision is made at this point, then the design specification would include no such requirement and the design organization would be free to design the item either as a repairable or as a non-repairable provided all other performance requirements could be met under either approach. However, consideration for a repair/discard decision at this time must include consideration for performance requirements and maintenance and support concepts as well as the economics of repair versus discard.

REPAIR vs. DISCARD

Decision Points



Either Government or contractor personnel could be involved in making the repair/discard decision at this point. Where Government personnel develop design specifications, a specific requirement might be added which stipulates the repair or discard characteristic. This is not generally the case, however, in the development of a major weapon system. It is more reasonable to expect that where Government personnel make the decision, such decisions are reflected in the Request for Proposal for Contract Definition and are stipulated with respect to major assemblies or to categories of similar types of subassemblies. When the contractor develops design specifications or subcontracts for the design of any part of the system, he is similarly involved in this decision point with respect to his subcontractors.

Initial Design or Item Selection

The second point of decision occurs during the actual design or design selection of the equipment. In the case of major weapon systems, the design is accomplished by the contractor's organization or his subcontractors with little or no guidance from the Government. If the performance specifications had stipulated specifically that an item would be repairable or non-repairable, there is, of course, no prerogative for the designer to exercise.

There seems to be a tendency for most design organizations to design a piece of equipment capable of being repaired. In most cases, however, the repairable design is not arrived at for the sake of facilitating repair per se, but rather by following conventional design practice. Some contractors interviewed by LMI suggested that the military tends to repair

rather than discard as evidenced through provisioning practices and that the contractor is motivated by such tendencies to design an item as a reparable even though a non-reparable design would sometimes result in a less costly piece of equipment. In fact, one contractor stated that after designing an item as a non-reparable, he had redesigned the item as a reparable in order to get engineering design approval.

Initial Source Coding (for Provisioning)

The third major point of the repair/discard decision is the time of Initial Source Coding for Provisioning. At this time, the items are also assigned "Recoverability Codes" to indicate whether they are reparable or non-reparable primarily for provisioning purposes. Thus, initial source and recoverability coding takes place during or prior to the initial provisioning conference. At this initial coding, we are concerned primarily with what spare parts we should provision for those items which are capable of repair. This decision is generally made by Government provisioning personnel with consideration given to the recommendations of the design contractor.

Coding/Design Review

A fourth point of decision is after an item has been introduced into the supply system, has been coded as a reparable or a non-reparable and for some reason this coding has been questioned. This point might be referred to as an after-the-fact review.

There are two major facets to this point of decision. The first is a review of the code--that is, if an item is reparable, should we continue to repair it or should we at this point code it as a non-reparable. If the item under

review had initially been designed specifically as a non-reparable, it may be difficult to reverse that decision without redesigning the item. However, the feasibility of redesigning the item as a reparable might be considered. Thus, the second facet of this point of decision is a design review. Such a review would often take the form of a value engineering approach and would consider all of the many factors required in a thorough value analysis. If this path is taken, we are in effect re-entering the item for consideration in the initial design decision point as depicted in Figure 1.

Repair Action

The final point of decision occurs when an individual piece of equipment has failed and some action must be taken regarding its repair or disposal. In most cases, if the item is either designed or coded as a non-reparable, there will be little question as to the action that will be taken. Where the item is coded as a reparable, however, some decision must be made based on the extent of the failure and the unit cost of the item under question. In many cases, a general rule-of-thumb has been used such as "if a coded reparable item can be repaired for less than 65% of the unit cost, it should be repaired."

ECONOMIC CRITERIA

Major Cost Elements

After examining all of the pertinent costs associated with repair or discard, we found it convenient to group these costs into the following ten major categories.

- Design Cost
- Initial End Item Procurement Cost

- Replacement Cost
- Preventive Maintenance and Operational Cost
- Corrective Maintenance Cost
- Supply Cost
- Cost of Specialized Corrective Maintenance, Tools and Test Equipment
- Documentation Cost
- Training Cost
- Disposal Value

Each of the major cost elements are briefly described on the following pages in terms of their principal subelements and the mathematical relationships among these subelements are indicated. The subelements identified and their mathematical relationships are not intended to suggest that there is only one method of calculating each major element of cost. It is rather intended that the major cost elements be described in terms that represent the most significant and sensitive factors inherent in each element and that such factors are broad enough for application in any environment where they may occur.

Before proceeding to discuss the major cost elements, it is necessary to identify the level of assembly to which the cost elements apply. In order for this analysis to be responsive to any level of assembly, we will refer in this study to any assembly that is being subjected to a repair/discard analysis as the "end item." The end item then consists of subassemblies and parts which will generally be referred to as component parts.

Design Costs (A)--Design cost consists of the engineering man hours and associated overhead necessary to design and qualify the end item in question.

This element of cost is pertinent to the repair/discard decision when the decision is made prior to actual design and in those cases where a re-design effort is considered. In order for design cost to have a bearing on the repair/discard decision, however, there must be two alternative designs in the offing--a reparable design and a discard design.

Contrary to most opinions, our discussions with design personnel led us to the conclusion that there were very few instances in which the design cost would be appreciably different for a reparable design as contrasted with a discard design. Appreciable differences in the design cost could often occur, however, in a re-design effort in either direction. For example, it may be determined at some point that an economic advantage could be gained by adopting a discard policy mainly through decreasing the unit cost of the item by re-designing it as a discard. In such an instance, there would of course be a design cost associated with the re-design of the item. A similar instance in which the design cost associated with a reparable design could be appreciably different from that associated with a discard would be where the design deviates from generally accepted design practices.

No attempt was made to subdivide the element of design cost into subelements since all design personnel interviewed in the course of this study unanimously agreed that estimating design costs is basically a matter of judgment. The accuracy with which this cost can be estimated or predicted is dependent by and large on the experience of the estimator with the type of equipment being designed. Quite frequently, design costs are a level of effort situation.

Initial End Item Procurement (B)--This cost element includes the initial cost to procure all end items required and

may be defined as the product of the end item population (p) and the end item unit cost (U). Thus, $B = (p)(U)$.

Both factors involved in determining the initial end item procurement cost are generally difficult to quantify early in the design stage. The actual value of the unit cost is difficult to predict in the design stage because unit cost is dependent upon a number of factors such as quantity to be procured, type of procurement contract, and degree of competition. The end item population is itself subject to discrepancies. One factor that contributes to such discrepancies is the fact that the program requirements, of which the end item under question is a part, often expand or contract during weapon system design phase.

In determining the real end item population, the application requirements of commonly used end items throughout an entire weapon or support system should be considered. For example, if a repair/discard decision is being considered for a particular size and type of electric motor aboard a ship, the end item population should, to be entirely correct, include all applications of electric motors of such size and type aboard the entire ship. In fact, it would be more realistic to consider the end item population in terms of all applications throughout the military departments and make the repair/discard decision with regard to all such types and sizes of electric motors.

Replacement Cost (R)--This cost element consists of two principal subelements. The first is the cost of replacing end items (E) and the second is the cost of replacing component parts (e).

If the entire end item is discarded at failure, then the component part replacement cost (e) would be zero. If the end

item is to be repaired, then the component part replacement costs (e) must be considered in addition to the end item replacement costs (E).

Even though the end item will be repaired, a number of end item replacements over and above that required under the end item population will be required in order to fill the supply pipeline and to replace those items which are condemned or wear out.

A discard decision with respect to a specific item which has failed or malfunctioned results in condemning that item from further use. Such condemnation action is based on the economics of repair versus discard with respect to one individual item at the time of failure. When a number of identical or similar items are considered collectively prior to the time of actual failure, the ratio of the anticipated number of items condemned to the total number of such items that fail is generally referred to as the "predicted condemnation rate." The predicted condemnation rate may also be expressed as the probability that any individual item in a group of items designated as reparable will, in fact, be more economically discarded instead of repaired.

It should be recognized that the actual condemnation rate reflects the results of repair/discard decisions made at the time of actual repair and thus these decisions are not based on economic elements which have already been incurred such as specialized test equipment, documentation, or training.

The end item replacement cost (E) may be stated as follows:

$$E = [c(L_s - L_d + P) + L_d] fU$$

Where c = condemnation rate

L_s = procurement lead time in years

- L_d = maintenance depot lead time or turn-around time to repair expressed in years
- P = program life in years
- f = number of failures per year
- U = unit cost of the end item

The derivation of the above equation is included as Appendix II. The failures per year (f) may be expressed as:

$$f = \lambda p h$$

Where λ = failure rate in terms of number of failures per operating hour

p = end item population

h = operating hours per year per end item

The procurement lead time and the depot turn-around time vary with the equipment, the type of program, the type of procurements and a number of other factors. However, both of these times are generally less than a year. Thus, predicting the supplier lead time and depot turn-around time based on experience and judgment should result in reasonably accurate prediction of the number of end items required to fill the pipeline. When the program life (P) is short, the depot turn-around time and procurement lead time have a more significant impact on the end item replacement cost.

The other factors involved in the end item replacement cost are of equal significance. That is to say, any increase or decrease in the condemnation rate, failure rate, item population, operating hours, or unit cost will result in a proportionate increase or decrease in the end item replacement cost.

The second major subelement of replacement cost is the cost of replacing component parts of the end item if it is

repaired. The component part replacement cost (e) may be mathematically described as follows:

$$e = (1-c)phP \sum_i (\lambda_i) (p_i) (u_i) (j_i)$$

Where c = end item condemnation rate
 p = end item population
 h = operating hours per year per end item
 P = program life in years
 λ_i = failure rate of component part i in terms of failures per operating hour
 p_i = parts population of component part i within the end item
 u_i = unit cost of component part i
 j_i = fractional system operating time in which the i^{th} component is operating

Preventive Maintenance and Operational Cost (M_p)--This category includes the cost of operating and caring for the end item and may be mathematically expressed as follows:

$$M_p = (h)(p)(P)(M_{p_1} + M_{p_2} + M_{p_3} + M_{o_1} + M_{o_2}) + M_{t_1} + P(M_{t_2})$$

Where M_{p_1} = preventive maintenance direct labor costs per operating hour
 M_{p_2} = material cost per operating hour
 M_{p_3} = preventive maintenance burden per operating hour, including administrative costs and transportation
 M_{o_1} = operational labor costs per operating hour
 M_{o_2} = operational material costs per operating hour
 M_{t_1} = initial costs to design and procure any specialized tools, test equipment or handling equipment required for preventive maintenance or operational use
 M_{t_2} = support cost per year associated with any specialized tools, test equipment or handling equipment required for preventive maintenance or operational use

Military Standard 778 defines preventive maintenance as "that maintenance performed to retain an item in satisfactory operational condition by providing systematic inspection, protection and prevention of incipient failure."

The subelements comprising preventive maintenance and operational cost may be thought of in terms of two basic parts--those which can be expressed as a function of operating hours and those which are more appropriately expressed as a function of the duration of the planned program life.

Where two alternative designs are considered, the design characteristics of one may require a different amount or type labor to operate the equipment. Moreover, there may be a difference in operational material cost including such things as fuel and power consumption. Where this is the case, factors M_{o_1} and M_{o_2} should be considered. Similarly, some alternative designs result in different requirements regarding specialized tools, test equipment or handling equipment in order to facilitate the preventive maintenance or in order to properly operate the equipment. When such tools, test equipment or handling equipment are required, there may be support costs associated with such equipment. When these cases prevail, factors M_{t_1} and M_{t_2} should also be considered.

The factors that are involved in the preventive maintenance and operational cost may be fairly well estimated during or at the completion of the design phase. Preventive maintenance costs may not be as easily identified, however, after the item has entered service use. This is because most maintenance depots do not draw a distinction between scheduled and unscheduled maintenance in accounting for labor and materials expended or in allocating the overhead burden.

Generally, preventive maintenance and operational costs are not highly sensitive to the total cost of repair versus discard unless there is a significant difference in the repair and discard alternative designs. Preventive maintenance and operational costs are, of course, only pertinent to the repair/discard decision when two alternative designs are in the offing.

Corrective Maintenance Cost (M_c)--This category includes the costs associated with "that maintenance performed to restore an item to a satisfactory condition by providing correction of a malfunction which has caused degradation of the item below specified performance."¹

$$M_c = (1-c)(F)(M_{c_x}) + (c)(F)(M_{c_y})$$

Where M_{c_x} = average corrective maintenance costs per failure that are incurred with respect to those items that are actually repaired and re-entered into the supply system for service use

M_{c_y} = average corrective maintenance costs per failure that are incurred with respect to those items which enter the repair cycle but are condemned before re-entering the supply system

c = condemnation rate

F = total number of failures over the program life

NOTE: $F = \lambda phP$

Where λ = failure per operating hour

h = operating hours per year per item

p = end item population

P = program life in years

There are several subelements of corrective maintenance costs which can be expressed in terms of average costs per failure as follows:

¹Corrective maintenance as defined in MIL-STD-778.

$$M_c = [M_{c_1} + M_{c_2} + M_{c_3} + M_{c_4} + M_{c_5} + M_{c_6} + M_{c_7} + M_{c_8} + M_{c_9}] F$$

Where M_{c_1} = labor cost of removal and replacement of the end item
 M_{c_2} = malfunction or failure diagnosis cost
 M_{c_3} = cost of transportation to the repair facility(s)
 M_{c_4} = cost of packaging, handling, shipping, etc.
 M_{c_5} = repair order processing cost
 M_{c_6} = actual repair labor cost
 M_{c_7} = material cost excluding component parts
 M_{c_8} = inspection and check-out costs
 M_{c_9} = corrective maintenance burden cost

The items that are repaired and placed back into the supply system will generally incur all elements of costs indicated above. The items that are condemned, however, will incur some of the above elements of cost in total and some only in part depending on what point in the repair cycle that condemnation is recognized.

Thus, each element of corrective maintenance cost may be expressed as follows:

$$M_{c_1} = (1-c)M_{c_{x_1}} + (c)M_{c_{y_1}}$$

Table 2 illustrates the interrelationships of corrective maintenance costs with a hypothetical case. The costs incurred by each element of corrective maintenance are indicated for each of ten item failures. Note that item failures 7, 8, 9 and 10 are found after some failure diagnosis to be uneconomical to repair and are subsequently condemned. Thus, the condemnation rate in this case is 40%.

The first cost of removal and replacement of the end item (M_{c_1}) is most pertinent to a repair/discard analysis when two

TABLE 2

HYPOTHETICAL CASE OF CORRECTIVE MAINTENANCE COSTS
INCURRED BY 10 ITEM FAILURES WITH 40% CONDEMNED

	<u>ITEM FAILURES</u>										TOTAL	INDIVIDUAL AVERAGE	COLLECTIVE AVERAGE
	1	2	3	4	5	6	7	8	9	10			
M_{cx1}	9	6	10	5	8	7					45	7.50	7.50
M_{cy1}							9	6	8	7	30	7.50	
M_{cx2}	47	53	60	40	55	45					300	50	40
M_{cy2}							15	35	20	30	100	25	
M_{cx3}	10	10	10	10	10	10					60	10	10
M_{cy3}							10	10	10	10	40	10	
M_{cx4}	15	15	15	15	15	15					90	15	15
M_{cy4}							15	15	15	15	60	15	
M_{cx5}	3	3	3	3	3	3					18	3	3
M_{cy5}							3	3	3	3	12	3	
M_{cx6}	60	70	80	120	100	110					540	90	54
M_{cy6}							0	0	0	0	0	0	
M_{cx7}	2	1	2	3	4	3					15	2.50	1.50
M_{cy7}							0	0	0	0	0	0	
M_{cx8}	18	20	16	24	23	19					120	20	12
M_{cy8}							0	0	0	0	0	0	
M_{cx9}	20	25	21	19	23	24					132	22	18.80
M_{cy9}							13	15	12	16	56	14	
M_{cx}	184	203	217	239	241	236					1,320	220.00	161.80
M_{cy}							65	84	68	81	298	74.50	

$$\begin{aligned} \bar{M}_c &= (1-c)(M_{cx}) + cM_{cy} \\ \bar{M}_c &= (.6)(220) + (.4)(74.50) \\ \bar{M}_c &= \$161.80 \end{aligned}$$

NOTE: $\bar{M}_c$ = average corrective maintenance cost per failure.

alternative designs are considered. There may be cases, however, where the end item can be repaired in place and hence, the removal costs are incurred only under a discard policy.

The cost to detect or diagnose the failure or malfunction in the end item (M_{c_2}) is perhaps one of the most volatile cost elements in the repair/discard analysis. In some cases, the cost to detect the cause of a failure represents the "lion's share" of expenditure in the repair cycle. In other cases, the cause of the failure is obvious on inspection, and hence, the cost of detection is negligible. Generally speaking, electronic equipment would be illustrative of the former case and mechanical equipment of a relatively stable technology would be illustrative of the latter.

The next two subelements of cost, packaging, handling and transportation to the repair facility (M_{c_3} and M_{c_4}) are both functions of the equipment design and the environment in which the equipment is used. In some cases, these two cost elements may be substantial and in fact, could be prohibitive to a discard choice where weight and size of the end item are extreme. Generally speaking, however, these two subelements of cost would be relatively small barring extreme physical characteristics of the equipment.

The remaining five subelements of corrective maintenance cost are basically functions of the repair operation. For example, the order processing cost and the corrective maintenance burden would reflect to a great degree the efficiency of the operational procedures employed in the repair facility. The work order processing cost (M_{c_5}) for an individual item which has failed is generally quite small due to the fact that work orders are often prepared for a large quantity of items at one time.

The actual repair cost (M_{C6}) varies significantly with the type of equipment considered and the type of failure. Actual repair costs are often estimated as an average cost for a given type of equipment. Once some maintenance experience has been gained with regard to a particular type of equipment, such estimates are generally fairly satisfactory. Our field investigations, however, led us to the conclusion that actual repair costs predicted at the time of design are often considerably inaccurate, but that such predictions could be significantly improved through better feedback of actual repair data.

The subelement of materials cost (M_{C7}) as used in this category does not include component parts which have already been discussed as a part of replacement cost. Materials in this sense refer to lubricants, preservatives, rivets, washers, etc. which in some cases may even be included under the overhead burden.

Inspection and check-out costs (M_{C8}) range from negligible to relatively significant. Electronic equipment again would be illustrative of the latter.

In summary, the most significant factors contributing to the corrective maintenance cost are the failure rate, failure diagnosis and failure repair. All three are difficult to estimate before the equipment has been designed and placed into service use.

Supply Cost (S)--This category of cost consists of those costs incident to procuring and stocking the required number of end items or component parts throughout the program life of the end item. The supply cost (S) may be expressed mathematically as follows:

$$S = s_1 + s_2 + s_3 + s_4 + s_5 + s_6$$

Where s_1 = cataloging cost
 s_2 = bin opening cost
 s_3 = item qualification testing cost¹
 s_4 = parts handling (receiving and storage) cost
 s_5 = inventory control cost
 s_6 = procurement cost

The initial cataloging cost (s_1) is the cost incurred in properly identifying the end item and its component parts, if appropriate, so that required spares may be procured and stocked. This includes securing a Federal Stock Number for the item and its component parts. The initial cataloging cost varies with the number of component parts which are planned as spares. In addition the initial cataloging cost will vary depending on whether the spare part components are peculiar to the end item or are common parts. Thus, the initial cataloging cost may be mathematically expressed as:

$$s_1 = n_p x_1 + (n_c)(x_2)$$

Where n_p = number of parts peculiar
 n_c = number of parts common
 x_1 = cost of cataloging a new item
 x_2 = cost of cataloging an existing item

The cost associated with initially cataloging a part peculiar may differ considerably from the cost of cataloging a common part. Common parts are generally subjected to pre-screening to determine whether they will need item descriptions in order to secure a new Federal Stock Number. The pre-screening cost is

¹Sometimes item qualifications testing costs are absorbed into the procurement costs, and hence, this cost would be included in the end item unit cost (U) and component part unit cost (U).

considerably less than the cost required to develop a full item description. The cost to develop proper item descriptions varies with the complexity of the item. For all practical purposes, however, a constant cost for parts peculiar and a constant cost for parts common should suffice for estimating the initial cataloging cost.

We have attempted in this study to identify the principal subelements of cost at a level which allows corresponding identification of the operational procedures which contribute to or determine the cost. Thus, the significant factors in determining the initial cataloging cost are the number of parts peculiar and the number of parts common which are required to be catalogued. The significant operational procedures are represented by x_1 and x_2 which are the cataloging procedures required for parts peculiar and parts common respectively.

In addition to the initial cataloging cost, there is often a cost associated with the physical opening of new stock bins for parts peculiar. This "bin opening cost" (s_2) may be expressed as a product of the number of parts peculiar (n_p) and some constant cost for new bin opening (x_3). Thus, $s_2 = (n_p)(x_3)$.

The next principal subelement of supply cost is the cost associated with qualification testing. This cost deals with qualifying suppliers for parts peculiar in the end item under analysis. The qualification cost (s_3) may be expressed as follows:

$$s_3 = (n_s)(n_p)(y_2)(x_4)$$

Where n_s = number of alternative suppliers expected to qualify their parts

y_2 = ratio of the parts peculiar which must be qualified to the total number of parts peculiar in the equipment

x_4 = average cost to qualify a part peculiar

The cost to qualify a particular part peculiar may, when appropriate, include the cost to the Government to obtain rights-in-data.

The three principal subelements of supply cost just discussed are introductory-type costs. That is, they are one-time occurring costs when the end item under analysis enters the supply system. Therefore, the first three elements of cost are pertinent to a repair/discard analysis only up through the initial source coding point of decision.

The next three subelements of supply cost (s_4 , s_5 and s_6) deal with the reoccurring cost necessary to supply the required number of end items or component parts throughout the program life. Thus, in each case, the program life (P) is a significant factor.

The parts handling and storage costs (s_4) include costs associated with receiving, preservation, storage and issuing of end items and component parts in order to facilitate repair or replace end items that have failed. These actual costs are dependent on the characteristics of each item and component part involved and should properly be expressed as:

$$s_4 = P \sum_i x_{5_i}$$

Where x_{5_i} = handling and storage costs per year for the i^{th} part

P = program life in years

In many cases the handling and storage costs of component parts do not vary significantly and thus such costs may be more simply expressed as:

$$s_4 = (P)(n)(\bar{x}_5)$$

Where $\bar{x}_5$ = average handling and storage costs per part per year including costs for inspection and maintenance or replacement of items that fail, break or are lost during storage.

n = number of component parts

P = program life in years

The inventory control cost (s_5) includes the administrative costs necessary to maintain records regarding demand rate, stock level and re-procurement actions. These costs may be expressed as a function of the number of component parts as follows:

$$s_5 = (P)(n)(x_6)$$

Where x_6 = inventory control cost per line item per year

n = number of component parts in the end item that are stocked

P = program life in years

The inventory control cost (x_6) depends on the inventory control operation and may vary depending on the operational efficiency at individual inventory control points.

The final element of supply cost is procurement cost (s_6) and includes those costs associated with placing a procurement for either the end item or the component parts. The cost for placing a procurement for parts peculiar, including the end item itself is often the only cost with which we need be concerned since common parts are often centrally procured in large quantities for many applications.

Procurement costs are more meaningful expressed in terms of the number of procurement transactions that take place rather than the number of failures which occur for each item procured. Thus, the economic order quantity associated with each part procured should determine the number of procurement transactions which are required. If the economic order quantity for each item procured is given in item units, the number of procurement transactions over the life of the program may be calculated by dividing the number of failures over the life of the program by the economic order quantity. If the number of procurement transactions are then multiplied by the cost to place a procurement transaction, the result is the total procurement cost over the life of the program for each individual item which must be procured. It is necessary to sum all such procurement costs in order to get the total procurement costs associated with the end item under analysis. Thus, the procurement costs may be mathematically expressed as follows:

$$s_6 = \sum_i \frac{(\lambda_i) (p_i) (h) (P) (x_7)}{(q_i)}$$

Where $(\lambda_i) (p_i) (h)$ = number of failures per year for the i^{th} item which must be procured

q_i = economic order quantity for the i^{th} item

x_7 = average cost per procurement transaction for parts peculiar

P = program life in years

Specialized Corrective Maintenance, Tools and Test Equipment (T)--Some end items will require specialized tools, test equipment or handling equipment in order to facilitate a corrective maintenance action. In these cases, the cost of providing such tools, test equipment or handling equipment should

be considered in the repair/discard analysis. Such costs may be expressed mathematically as: $T = (t_1 + t_2 + t_3)(g)$

Where t_1 = design costs associated with specialized equipment
 t_2 = initial investment cost
 t_3 = replacement and support cost over the program life
 g = allocation factor

When the tools, test equipment or handling equipment are required exclusively for corrective maintenance and are not necessary to the production or inspection operations, a cost to design such tools, test equipment or handling equipment (t_1) will be incurred and should be considered. All of the aspects of this element of cost (t_1) are similar to those already discussed under the element of design cost (A) for the end item.

The next principal element (t_2) of this category of cost is the initial investment required for such tools, test equipment and handling equipment. Simply stated, this initial investment is a product of the number of units required and the cost per unit. It is of particular interest to note that the number of units required is dependent on the decision regarding the echelon of maintenance at which repair will take place. In other words, will the item under analysis be repaired in the field, or at the base or will it be repaired at intermediate or depot echelons, and if at depot level, will it be repaired at all depots or just one?

Finally, the cost associated with replacement and support of specialized equipment (t_3) over the program life must be considered. Here we are concerned with all of the same cost elements that would be subjected to a repair/discard analysis for the end item.

There is a final consideration that should be made in determining the cost of specialized corrective maintenance, tools, test equipment and handling equipment. This consideration has to do with the capability or feasibility of employing the use of such equipment to other than the end item being considered for repair or discard. This consideration is included as an allocation factor (g).

This cost category (T) has its greatest impact on the repair/discard decision early in the design stage--before the specialized equipment is actually designed. However, this cost category should be considered at any point of analysis since the replacement and support costs associated with the specialized equipment continues throughout the life of the equipment. There are no evident constants or uniform costs which can be employed in predicting the cost of specialized corrective maintenance equipment. Each situation is unique and must be evaluated within its own requirements and intended use.

Documentation Cost (D)--Although the term documentation is broad and covers a wide variety of types and kinds of documents, we will for the purposes of this analysis group all documentation costs into four major subelements as follows:

$$D = d_1 + d_2 + d_3 + d_4$$

Where d_1 = drawings and parts lists
 d_2 = maintenance manuals
 d_3 = operational and training manuals
 d_4 = specifications

A number of documents are generated in the course of designing, manufacturing, and placing in the military supply system a new item of equipment or subassembly thereof. Many

such documents are inherent in the performance of required operations. When two alternative designs (reparable and non-reparable) are considered, all documentation costs associated with each design should be considered. Most of these costs would normally be considered as part of the design cost. For example, drawings that are required in the normal course of designing an item of equipment would be included in any analysis of design cost. However, there may be requirements outside of the design operation for which drawings are needed, such as competitive reprourement, maintenance or training. In these cases, documentation costs are often considered as separate line items of procurement and are in fact required to be listed as such. It is these types of documentation costs with which we are concerned in this cost element.

All four subelements of documentation cost should be considered when two alternative designs are in the offing. Once the design has been established, however, only those increments of documentation cost which are specifically required for corrective maintenance should be considered. In most cases, only that element dealing with maintenance manuals is directly attributable to the corrective maintenance operation, and even here the requirements for preventive maintenance or operation of the equipment often overlap or are redundant to those requirements for corrective maintenance.

Training Cost (W)--This element of cost consists of two principal subelements--the cost of training maintenance personnel and the cost of training operating personnel. Training costs (W) may be expressed mathematically as:

$$W = w_1 + w_2$$

Where w_1 = maintenance training cost
 w_2 = operational training cost

Whether the training is directed toward maintenance personnel or operating personnel, the costs incurred include instructor and instructee man hours, instruction material or training aids, instruction facilities and other such costs incident to the training program such as transportation or per diem costs. These costs vary from equipment to equipment and in fact are often difficult to identify as being associated with a specific item for which a repair/discard analysis is desired.

To be correct, an allocation factor should be included in the above equation as was done in the case of specialized maintenance tools, test equipment and handling equipment. Such an allocation factor has been omitted, however, since it might be debatable as to the way in which training costs should be allocated. For example, should a basic training course in electronics given to a potential maintenance trainee be prorated over all electronic repairs that the trainee will eventually undertake; or should such costs be prorated only over the repairs associated with a given weapon system; or should such costs be prorated over an average employment life of such trainees.

Properly allocating the cost of developing a maintenance capability is considerably more diffuse and complex than allocating the cost of designing and procuring a specialized piece of test equipment. If it is difficult to allocate training costs, it is even more difficult to predict such training costs with respect to a specific item. Like design costs then, training costs are basically determined through experience and judgment.

Operational training as well as maintenance training is pertinent to the repair/discard analysis when two alternative

designs are being considered. Once the design has been selected, however, only that training associated with maintaining and repairing the item is pertinent to the analysis.

Although training costs may be appreciable when viewed from the basis of a total weapon system, it is usually relatively insignificant when attempting to allocate specific portions of the training cost to an individual item which might be considered for a repair/discard decision. Thus, training costs are generally significant to a repair/discard analysis only when many items within a common category or class are subjected as a single entity to a repair versus discard choice.

Disposal Value (V)--A final element of cost associated with a repair or discard choice is the economic liability or asset incurred by the Government when an end item is condemned and disposed. This is the only element of cost which may turn out to have a negative value, which results when the reclamation value of the end item is greater than the disposal cost. This asset or cost is a function of the number of failures and the condemnation rate and may be mathematically expressed as:

$$V = cfP(v_1 - v_2)$$

Where v_1 = disposal cost
 v_2 = reclamation value of the end item
 c = condemnation rate
 f = number of failures per year
 P = program life in years

Most of the studies reviewed by LMI either failed to consider this element of cost or asset, or considered such cost to be insignificant. The lack of consideration of this element

of cost is probably due to the fact that such cost or assets are difficult to estimate. The volume of items considered for disposal will often have a great deal to do with the disposal value. Not only are the condemnation rate and the failure rate difficult to predict during design or even at the initial source coding, but the reclamation value of the end item under question usually requires knowledge as to the extent and type of failures and a "market" plan. Thus, this element of cost is probably more easily handled at the coding/review point than it is prior to that point.

Effect of Repair on Item Reliability

It is generally assumed that an item which has failed and been repaired is restored without degradation of its original performance characteristics. The question arises, however, as to whether a repaired item is equally as reliable as a new one. There appears to be varying opinions on this subject even with respect to the same type of items or the same repair facility. We pursued this subject throughout the study, but could find no conclusive evidence that any type or category of equipment normally resulted in a degradation or aggradation of reliability due to corrective maintenance.

Many individuals interviewed, however, insisted that a degradation or aggradation of reliability did result from corrective maintenance, and could be quantified if controlled tests were established. In those cases, therefore, where the reliability is known or expected to be different for repaired items, the failure rate (λ) where it appears in the repair/discard decision model should be corrected in accordance with the following relationship; the derivation of which is included as Appendix III.

$$\lambda = \frac{1 + (\lambda_r) (h) (P) - \frac{\lambda_r}{\lambda_o}}{hP}$$

Where λ_o = failures per operating hour for new items

λ_r = failures per operating hour for repaired items

h = operating hours per year

P = program life in years

If the repair/discard decision is being considered with respect to a single end item at the time of failure, then the repair costs should be multiplied by the ratio $(\frac{\lambda_r}{\lambda_o})$ where the reliability of the repaired item is expected to be different.

Criteria Sensitivity at Major Decision Points

The major cost elements discussed in the previous paragraphs are intended to represent a grouping of all major costs associated with a repair or discard choice if an analysis were being made before the item in question had been designed. Thus, each major cost element may have different degrees of sensitivity to the analysis depending on the point in the life cycle where the repair/discard analysis is considered. The next step then is to analyze the impact of the aggregation of the major cost elements on the repair or discard choice at the major points where such decisions could be considered. Figure 2, "Hypothetical Application of Cost Elements at Major Point of Decision," should aid in following this analysis. It identifies each of the major cost elements and each of the major points of decision already discussed.

Each of the major cost elements intersects the repair and discard columns at each major point of decision. An X in the intersection indicates that the cost element is applicable at

X PERTINENT
 .. NOT PERTINENT

FIGURE 2

HYPOTHETICAL APPLICATION OF COST ELEMENTS AT MAJOR POINT OF DECISION

MAJOR COST ELEMENTS	DEVELOPMENT OF DESIGN SPECIFICATION		INITIAL DESIGN OR ITEM SELECTION		INITIAL SOURCE CODING		CODING REVIEW		DESIGN REVIEW		REPAIR ACTION	
	REP.	DISC.	REP.	DISC.	REP.	DISC.	REP.	DISC.	REP.	DISC.	REP.	DISC.
DESIGN COST	X	X	--	--	--	--	--	--	X	X	--	--
INITIAL END ITEM PROCUREMENT	X	X	X	X	--	--	--	--	--	--	--	--
REPLACEMENT COST	X	X	X	X	X	X	X	X	X	X	X	X
PREVENTIVE MAINTENANCE & OPERATION COST	X	X	X	X	--	--	--	--	X	X	--	--
CORRECTIVE MAINTENANCE COST	X	--	X	--	X	--	X	--	X	--	X	--
SUPPLY COST	X	--	X	--	X	--	--	--	X	--	--	--
SPEC. CORR. MAINT. TOOLS, TEST & HANDLING EQUIP.	X	--	X	--	X	--	--	--	X	--	--	--
DOCUMENTATION COST	X	X	X	X	X	--	--	--	X	X	--	--
TRAINING COST	X	X	X	X	X	--	--	--	X	X	--	--
DISPOSAL VALUE	X	X	X	X	X	X	X	X	X	X	X	X

that point under the indicated repair or discard choice. Two hyphens (--) at the intersection indicate that the cost element at that point is either not pertinent, is insignificant, has already been incurred, or that the cost is ostensibly the same for either a repair or discard choice and thus should no longer be considered.

Development of Design Specifications--At this early point of decision, all of the major cost elements are pertinent to the repair/discard analysis since at this time the item in question has not even been designed. It will be noted in Figure 2 that no cost is incurred under the discard choice for corrective maintenance, supply, and specialized corrective maintenance tools, test equipment and handling equipment. These cost elements are ostensibly attributable only to a repair policy.

Actually, there is a supply cost associated with the discard choice insofar as the end item being analyzed is concerned. However, since the end item must be supply-managed under either a repair or discard policy and since we are primarily interested in the difference between repair and discard cost, the supply cost may be considered only with respect to the component parts of the end item and hence, for all practical purposes, be considered as zero under the discard policy.

The cost of documentation and training could similarly be considered as only attributable to a repair choice if we were concerned with only one design configuration. However, since there must be two alternative designs in the offing in order to even invite a repair/discard decision during the design procurement stage and since the documentation and training required are directly associated with the characteristics of

the design, these elements of cost should properly be considered under both the repair and discard approach. For the same reasons, preventive maintenance and operational cost as well as disposal value should be considered for both alternative designs.

All of the cost elements mentioned are difficult to predict at this stage of the life cycle unless the item with which we are concerned is one which represents a rather stable technology and where a great deal of experience is available regarding the maintenance of such items. The first three cost elements, i.e., design cost, initial end item procurement and replacement cost--are by far the most significant cost elements to consider at this stage of the life cycle.

A repair/discard decision at this point results in specifying the end item as a reparable or as a discard. No stipulation at all regarding repair/discard defers the decision to a later point. Deferment of the decision should be based on the economic advantage of making the decision early as contrasted with the increased accuracy with which the decision can be made later.

The design cost may be considered as the only major cost element that is applicable at development of design specifications but not at actual design. There are two reasons for not considering design costs at the point of actual design. First, if there is sufficient information concerning the item to allow identification of appreciable differences in the repair versus discard design costs, then it is almost certain that sufficient information concerning repair versus discard item characteristics is available to make the decision prior to actual design. Appreciable differences in design costs generally occur when

one of the designs represents conventional design practices and the other does not. In order to estimate these differences, however, considerable information is required regarding the item characteristics associated with the unconventional design approach. Second, if sufficient information concerning item characteristics is not available to allow the repair/discard decision to be made, then some actual design with respect to one or both design alternatives must take place. The cost of such actual design is already incurred by the time the designer is able to make a repair/discard analysis, and hence, such costs should not be considered. However, if at the time of analysis the remaining design costs associated with the repair or discard design approach are known to be appreciably different, then such costs should be considered. Normally, this is not the case.

The ability to accurately predict costs associated with repair and discard designs is unquestionably greater at the point of actual design. For example, the replacement cost (see Page 18) is a function of the number of failures per year, the unit cost and the condemnation rate. It is difficult without the benefit of an actual design to predict any of these factors with a very high degree of accuracy.

Initial Design or Item Selection--All of the cost elements are applicable at the time of actual design or item selection with the exception of the design cost.

As in the case of the prior point of decision, the cost elements of "initial end item procurement" and "replacement" are the most significant at the time of actual design. Moreover, the designer is in a better position at this time to estimate failure rates, maintainability, and unit cost. The

ability to predict corrective maintenance cost and the condemnation rate has improved, but both are still subject to a great deal of speculation. Two of the major cost elements take on a higher degree of significance at the time of actual design. The first is the preventive maintenance and operational cost. Second, the requirements for specialized tools, test equipment or handling equipment under a repair policy become more definitive.

Initial Source Coding (for Provisioning)--At this point of decision, there are no longer two alternative designs to consider. The item under analysis has been designed and the question is now whether the policy should be to repair or discard at failure. There is only one unit cost to consider and only one end item failure rate. The initial end item procurement cost and the preventive maintenance and operational cost may be considered as being equal under either a repair or discard policy. The cost of documentation and training may be considered only for those documents and that training required under a repair policy. Documentation and training required for operation is the same under either a repair or a discard policy.

The most significant costs at this point of decision are the replacement costs and corrective maintenance costs. The ability to predict both of these cost elements has improved over the preceding point of decision for several reasons. First, since the design is now more definitive, it enables the initial source coder to better associate the item under analysis with similar classes of equipment for which historical information regarding failure rates, condemnation rates and corrective maintenance cost may be available. Second, the

initial source coder is in a better position to analyze groups of items to realize an economic advantage in corrective maintenance planning. In other words, if a number of similar items are considered simultaneously, it may become apparent that the corrective maintenance costs will be less due simply to the volume of items involved. By the same token, there may be an opportunity to gain an economic advantage where specialized tools, test equipment or handling equipment are required.

It is important to recognize that a decision at this point to adopt a discard-at-failure policy generally results in immediate action to procure more end item spares rather than component part spares.

Coding Review--It was stated earlier that the time of review could occur at any time after an item has entered the supply system. Thus, the initial cost associated with supply, specialized tools, test equipment and handling equipment, documentation and training would have already been incurred. Although all such cost elements contain continuing costs, these have been indicated on Figure 2 as insignificant compared to the initial costs. All cost elements at the time of review are of course dependent on the remaining program life of the item under analysis.

As in the case at initial source coding, the replacement cost, corrective maintenance cost and disposal value are the most significant cost elements to the review analysis. There is a distinct advantage at the time of review since actual quantitative data are usually available regarding failure rates, unit cost, corrective maintenance cost and disposal value. One additional advantage at the time of review is the ability to improve the efficiency of the procurement and maintenance

operations against the background of knowledge and data assimilated through operational use of the equipment.

Design Review--A design review might be undertaken with regard to either an item that has been coded as a reparable or an item that has been coded as a discard. In either case, there are three initial prerequisites to a design review. (1) There must be some indication of a potential economic advantage achievable through an alternative design. Such economic advantage might be found in the decrease of unit cost or the decrease of failure rates, (2) the volume of items involved and the program life must be of sufficient magnitude to justify a design review, and (3) the expected cost of redesign must not render the potential savings insignificant.

If a design review is justified and hence undertaken, all of the cost elements pertinent at the point of actual design are again pertinent with the same degree of relative significance. The one difference will lie in the fact that the quantitative values of the various cost elements will tend to be somewhat more reliable. A design review of a repair/discard decision actually constitutes a logistics activation of a value analysis project. Value analysis projects have historically been activated principally by engineering personnel and for engineering or design improvements. Since there is sometimes a scarcity of engineering talent available to identify equipments which have redesign potentials, the proponents of value analysis should be encouraged by the presence of a logistic catalyst.

Repair Action--At the point of a specific repair action, the cost elements pertinent to the repair/discard decision have narrowed to include only the replacement cost, the corrective

maintenance costs, and the disposal value. Moreover, these three cost elements are applicable to a single piece of equipment or to a small lot of similar pieces of equipment. Since we are dealing at this point with an item or items that have already failed, the failure rate need no longer be considered unless a repair action is known to result in a degradation or aggradation of reliability (see Page 38). Generally, we need only weigh the unit cost of the item against the cost of repairing it less the disposal value. At this point, the quantitative data is perhaps at its highest degree of accuracy in that we are concerned with a specific item in a specific repair facility. When the decision is deferred to this point, however, much of the costs associated with a repair policy have already been incurred and the opportunity for economic advantage via discard has been decreased.

DEVELOPMENT OF SCREENING RULES

In order to achieve the economic advantage that may be associated with either a repair or discard choice, it is necessary to first determine the costs incurred under each respective choice. The point has already been made that it is not feasible to make an exhaustive economic analysis with regard to every item or assembly entered into the military supply system. Yet there may be an appreciable economic advantage associated with the correct repair/discard choice for any such items or assemblies. It is desirable, therefore, to establish a method of screening "end items" to determine whether the repair/discard choice is apparent, warrants an exhaustive economic analysis or should be deferred to a later decision point.

Before discussing unique screening rules at each major point of decision, two general screening rules should be established. First, one should presume that the item under analysis will be repaired unless a discard choice has been justified. It has been demonstrated that a discard choice at development of design specifications, actual design, or initial source coding often makes it difficult, if not impossible, to subsequently reverse that decision. A repairable item, on the other hand, can always be discarded.

The second general screening rule addresses the level of assembly at which the repair/discard screening process should take place. The rule suggested is that the repair/discard analysis should be directed initially toward the highest level of assembly and proceed to the next lower level until a discard policy is justified. The alternative to this approach is to seek an optimum combination of repair/discard choices with regard to the various subassemblies of the end item. This alternative approach requires a repair/discard analysis beginning with the lowest level of assembly and proceeding to higher levels based on preceding analyses. A particular subassembly (X) in an isolated situation may be more economically repaired than discarded although the end item of which it is a part has been justified as a discard. This does not mean, however, that the end item has been justified as a discard erroneously, nor that it is less costly to repair the end item when subassembly (X) fails. The costs to determine that subassembly (X) has failed may be appreciable. Moreover, when subassembly (X) fails, it may cause extensive additional damage to the end item. If the lower-to-higher level of assembly approach is taken, considerable analytical costs are incurred and the result does not necessarily improve the repair/discard analysis with respect to the end item.

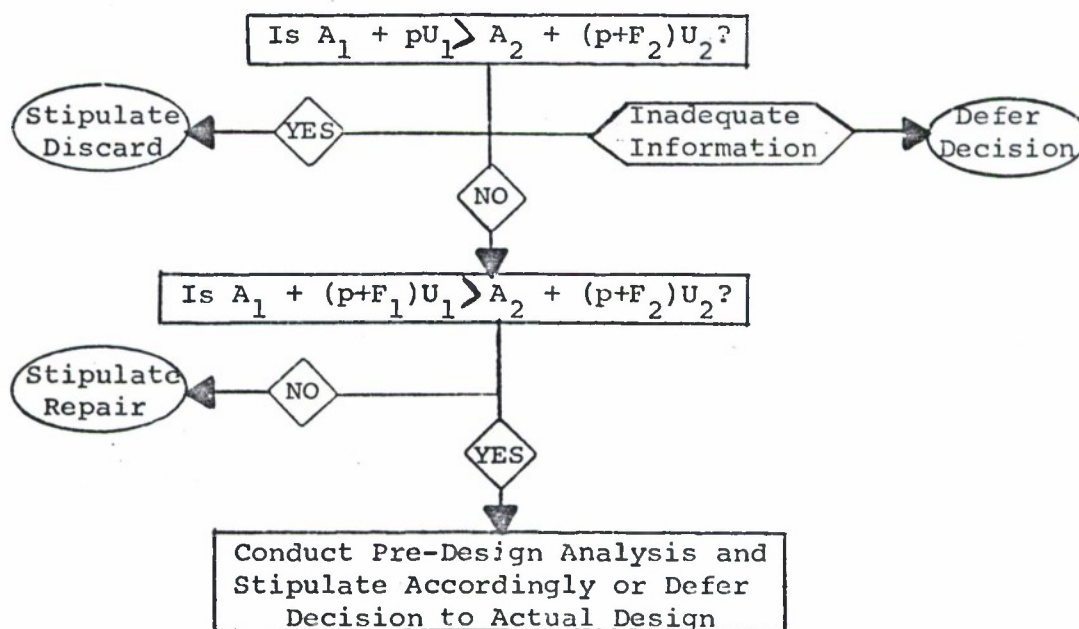
In those cases where the same subassembly is used in two or more assemblies which are designed by different organizations, the prime contractor's design organization must provide coordination among the various design organizations to insure identical repair/discard decisions. This is much the same problem as insuring that intra-system standardization takes place.

Unique screening rules for each repair/discard decision point consonant with the two general screening rules previously discussed are presented in the following sections. The screening rules are stated in the form of narrative and algebraic questions to the analyst.

Development of Design Specifications

Screening Rule 1--Is the sum of the anticipated design cost and the initial end item procurement cost for the reparable design sufficiently greater than such costs associated with the discard design to justify a repair/discard decision at this time?

Algebraic Expression:



Where p = item population
 U_1 = unit cost of reparable design
 U_2 = unit cost of discard design
 A_1 = reparable design cost
 A_2 = discard design cost
 F_1 = anticipated number of failures over program life
for reparable design
 F_2 = anticipated number of failures over program life
for discard design

Discussion--A repair/discard decision made at this early point in the life cycle results in a design specification requiring the item to be either a reparable or a discard. Deferment of the decision allows the designer during the actual design of the item to consider the pros and cons of repair/discard.

There are two primary advantages of making the repair/discard decision prior to actual design if practical to do so. First, such decisions may be directed at similar types of item or items performing similar types of functions within a major system or program, and thus provide a basis for greater uniformity in the maintenance and support of such systems or programs. This may be a particular advantage when a large number of design organizations are involved. Second, it allows full advantage to be taken of the difference in design costs where such costs are significant.

In order to consider a repair/discard decision at this point, reasonable approximations of the design costs, unit costs, number of failures, and item population are required. If such information is not available, the decision should be deferred.

The first step of the screening process is to compare the design costs and initial item procurement costs for the reparable design with the design costs, initial item procurement costs, and the replacement costs for the discard design. If the sum of the discard costs is less than the sum of the repair costs considered in the comparison, then the item should be specified as a discard. If not, then an additional comparison should be made after adding the replacement costs of the reparable design under the assumption that the reparable design will ultimately be discarded. If the repair costs are still less than the discard costs, then the reparable design should be specified, since even under a discard policy the reparable design is more economical.

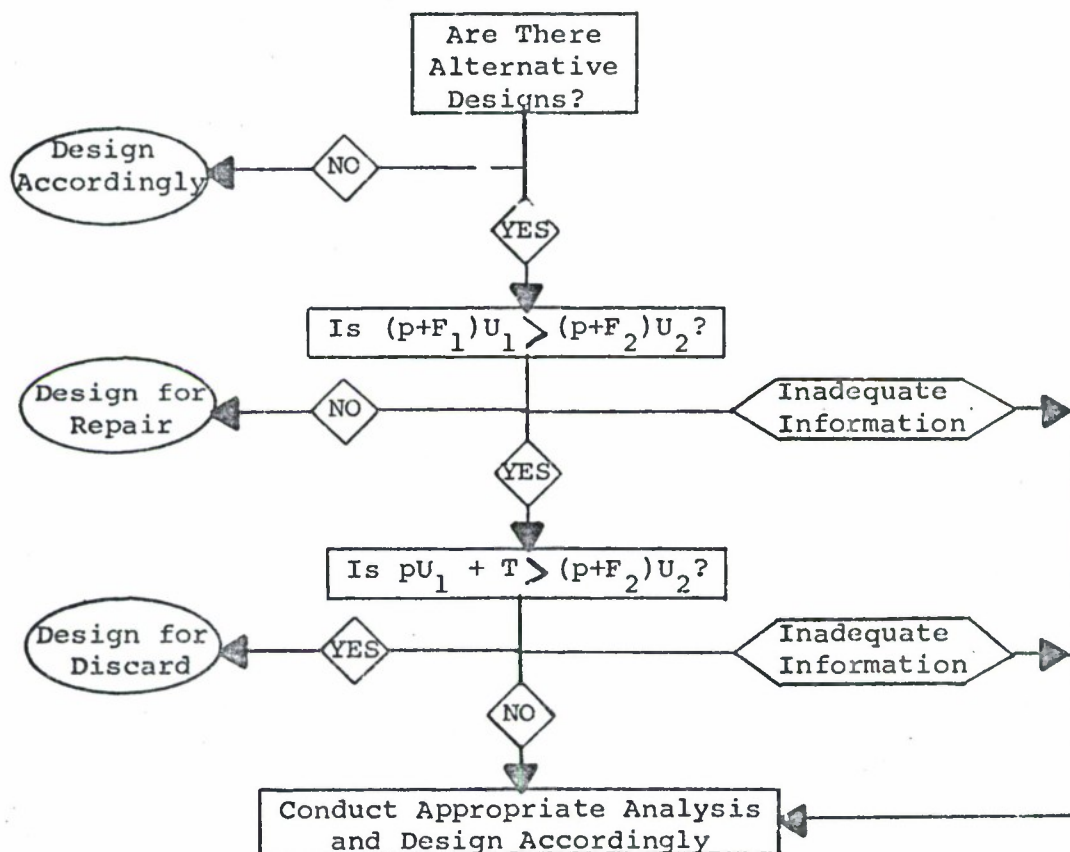
If the repair costs under the second comparison are greater than the discard costs, then additional cost information regarding the reparable design is required in order to make the repair/discard decision. Since in most cases, it is too early in the life cycle to estimate with reasonable accuracy additional costs associated with repair, the repair/discard decision should be deferred.

Initial Design or Item Selection

Screening Rule 1--Are there alternative designs for repair and for discard?

Screening Rule 2--Does the anticipated unit cost and failure rate for the discard design justify further consideration for the discard design?

Screening Rule 3--Is the sum of the anticipated costs for initial end item procurement and specialized test equipment for the reparable design great enough to justify a discard design?

Algebraic Expression:

Where p = item population

U_1 = unit cost of reparable design

U_2 = Unit cost of discard design

F_1 = anticipated number of failures over program life for reparable design

F_2 = anticipated number of failures over program life for discard design

T = anticipated design acquisition and support costs for specialized test equipment, tools, or handling equipment for reparable design

Discussion--It is first determined that there are two alternative designs to consider. Next, the costs associated with the reparable design is compared with the costs associated

with the discard design in terms of significant factors at the time of design that can be reasonably approximated by the design organization.

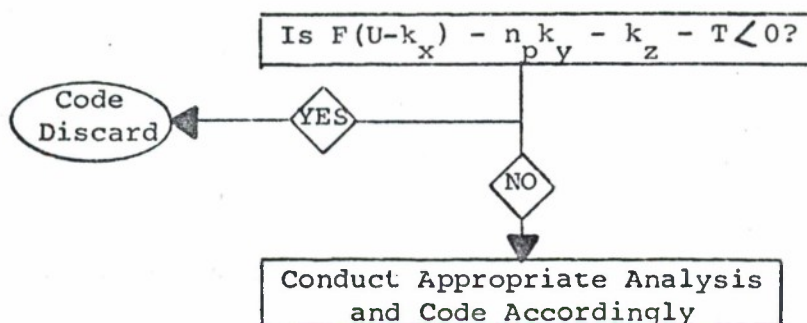
Generally, the economic advantages of designing an item specifically as a discard rather than as a reparable are that the unit cost and failure rate of the item tend to be lower; and the cost of designing, procuring and supporting specialized maintenance equipment is often avoided.

Two comparisons are made of the costs associated with the reparable design and those associated with the discard design. The first compares approximate life cycle costs for the discard design with similar approximate costs for the reparable design on the assumption that the reparable designed item will actually be discarded. This comparison allows an appraisal to be made regarding the effect of different unit costs and failure rates. Unless the costs under a discard policy for the reparable design are greater than such costs for the discard design, there is no economic advantage in a design for discard.

If further analysis is indicated, the second step is to compare the approximate life cycle costs for the discard design with selected major costs associated with the reparable design under a repair policy. The selected major costs are initial end item procurement (pU_1) and the costs of specialized maintenance equipment (T). If the sum of these selected major cost elements is greater than the sum of the anticipated initial end item procurement (pU_2) and replacement costs (F_2U_2) for the discard design, then the discard design is definitely justified. If not, then an economic analysis in greater depth is required.

Initial Source Coding (for Provisioning)

Screening Rule 1--Is the approximate cost to discard significantly less than the minimum cost to repair?

Algebraic Expression:

Where F = anticipated number of end item failures over program life

U = unit cost of end item

T = anticipated design acquisition and support costs (not yet incurred) for specialized test equipment, tools, or handling equipment to facilitate corrective maintenance

n_p = number of parts peculiar in end item

k_x = minimum costs to enter an item into the repair cycle

k_y = minimum cost to introduce a new part into the supply system

k_z = minimum approximation of additional costs incurred under a repair policy for such things as documentation, training, and supply

Discussion--The costs incurred under a discard policy can be approximated with reasonable accuracy as the product of the anticipated number of failures and the unit cost (FU). It is considerably more difficult to approximate the costs incurred under a repair policy. The screening rule, therefore, suggests comparing the approximate discard costs to a minimum repair cost in order to avoid where possible detail calculations and costly analyses. We believe that there are several factors which may be treated as economic constants with respect to similar types or categories of equipments. Such factors are

helpful in establishing a minimum cost under a repair policy and thus can aid in rapidly identifying those items or assemblies which definitely result in an economic advantage through a discard policy.

The first factor is indicated by k_x and represents the minimum cost to enter any item of a given type into the repair cycle at a particular repair facility. In the case of the MINUTEMAN missile system, for example, \$18.46 could be identified as a minimum cost incurred by any item entering the repair cycle.

The second factor is indicated by k_y and represents the minimum cost to enter a new part into the supply system. The cost of new item entry into the supply system varies among other things with item complexity, but there are certain procedural functions which are applicable to all items which enter the system--\$207 has been suggested as a reasonable figure for entering a new part into the supply system.¹

The third factor is indicated by k_z and represents a minimum approximation of additional costs incurred under a repair policy for such things as documentation, training, and supply. Such costs, of course, vary with the type of equipment, but for selected categories of similar types of equipment, a minimum cost could be established with relative ease.

Another way of interpreting the factor k_z is as an insignificant differential in repair and discard costs.

We reviewed many items which had been subjected to repair/discard analysis in-depth. It was observed that the cost to

¹LMI report, "Life Cycle Costing in Equipment Procurement," April, 1965, Page 35.

repair and the cost to discard with respect to many of these items were surprisingly close. In such cases, there is little to be gained or lost through a repair/discard choice. For example, a recent study conducted by the Vendor Repairable Items Panels of the Joint Spare Parts Committees of the AIA/EIA cited 19 cases where the cost to repair and to discard vendor items, valued from \$13 to \$3,917 had been determined. Looking at these 19 cases in terms of savings per year to the Government through the appropriate repair/discard decision, we find that 4 of the 19 cases would have resulted in less than \$100 per year savings, and that 11 of the 19 cases would have resulted in less than \$500 per year savings. When one examines the many opportunities for quantitative error, it is difficult to say in many cases whether it is more advantageous to repair or to discard, and in fact, it is difficult to avoid the conclusion that there are many items where the difference in repair and discard costs is insignificant.

The costs incurred by a requirement for specialized test equipment, tools, or handling equipment is indicated by (T) and can, where such equipment is required, be very significant in determining the repair or discard choice. Such costs should be estimated for each individual case.

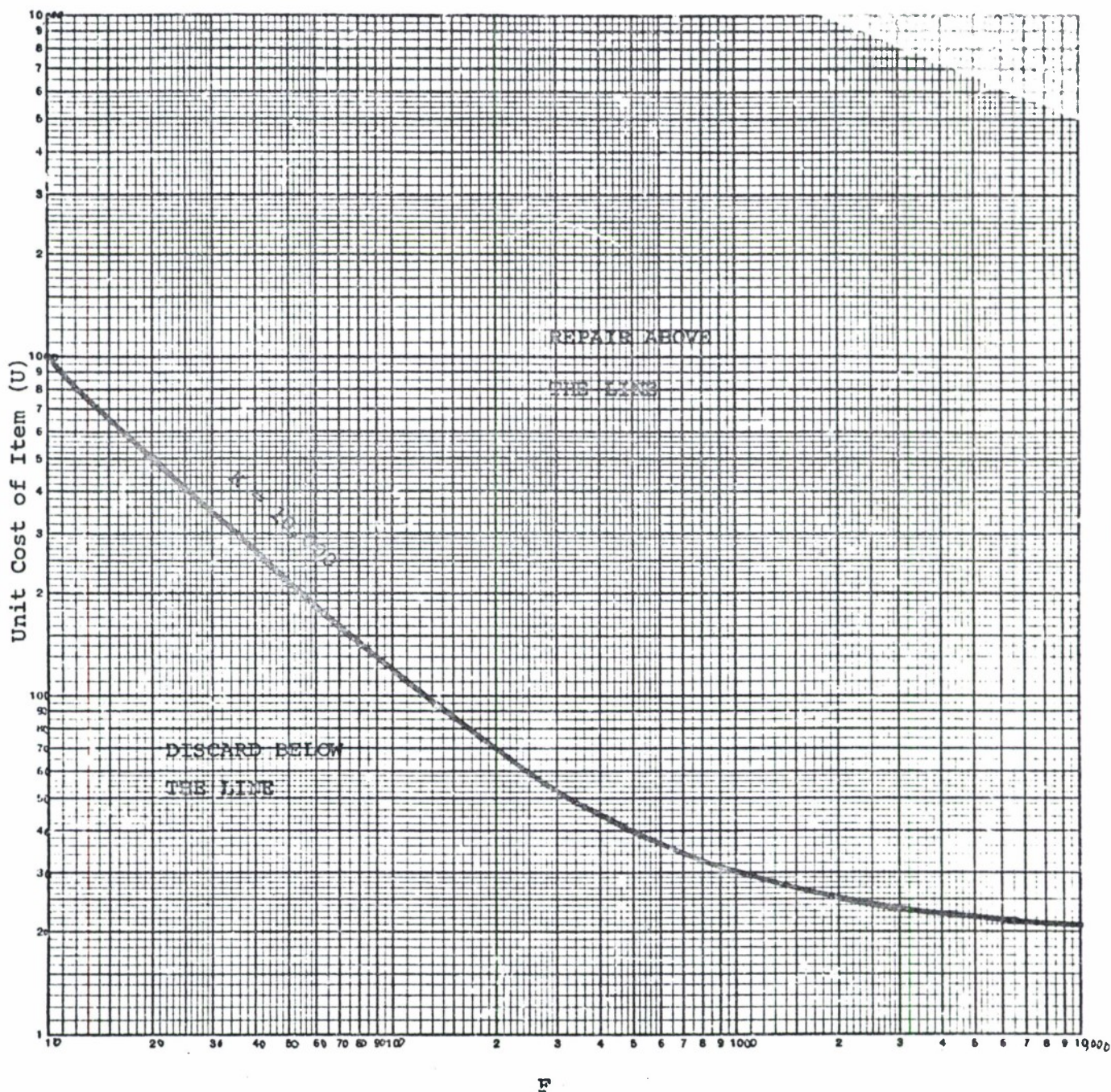
The screening rule for initial source coding may be illustrated graphically as shown in Figure 3 where "K" represents $n_p k_y + k_z + T$. Suppose that the minimum cost to enter an item into the repair cycle $k_x = \$20$ and that the other factors in the screening rule have the following values:

$$\begin{aligned}(n_p)(k_y) &= (15)(\$200) = \$3,000 \\ k_z &= \$2,000 \\ T &= \$5,000\end{aligned}$$

$$\text{Thus, } F(U-\$20) - \$10,000 = 0$$

FIGURE 3

GRAPHIC ILLUSTRATION OF INITIAL SOURCE CODING
SCREENING RULE FOR REPAIR/DISCARD DECISIONS



Total anticipated failures over
the program life of item

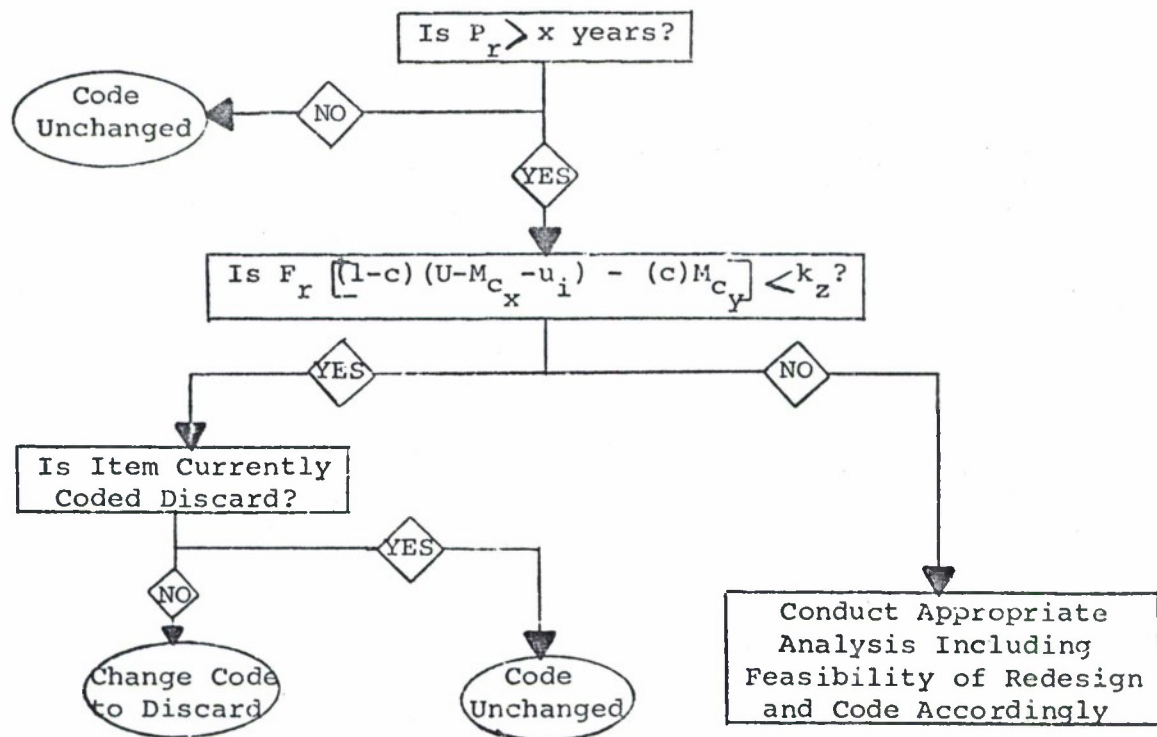
when the cost to repair and the cost to discard are equal. If the coordinates of unit cost (U) and total anticipated failures (F) fall below the break-even line, then a discard policy is justified.

Coding/Design Review

Screening Rule 1--Is the remaining program life sufficient to warrant a change in the repair/discard code?

Screening Rule 2--Is the remaining cost to discard significantly less than the remaining cost to repair?

Algebraic Expression:



Where P_r = anticipated number of remaining years in program life

x = minimum number of remaining years in program life for considering a change in repair/discard code

- F_r = total number of anticipated failures over the remaining program life
 c = condemnation rate
 U = end item unit cost
 $\bar{u}_i$ = mean component part costs per failure
 M_{c_x} = average corrective maintenance cost per failure for items that are not condemned
 M_{c_y} = average corrective maintenance cost per failure for items that are condemned
 k_z = minimum approximation of additional costs incurred under a repair policy for such things as documentation, training, and supply

Discussion--At the time of review, fairly accurate data is generally available regarding the failure rate, condemnation rate, and corrective maintenance costs. Thus, the screening rules for initial source coding can be rather realistic.

The first step is to eliminate from further consideration those items where the remaining program life is too short to justify changing the repair/discard code even if the current policy is uneconomical. The remaining program life required to justify a change may vary depending on the item and the type and number of spare parts already in stock. However, it seems reasonable to establish a minimum number of years for screening purposes of perhaps two to three years.

The major cost elements considered in the second screening rule at this point in the life cycle are the replacement costs, the corrective maintenance costs and the minimum approximate costs for documentation, training, and supply represented by k_z . The rule compares the approximate discard cost with the approximate repair cost and is developed as follows:

Let D_c = Approximate discard cost

R_c = Approximate repair cost

$$D_c = F_r U$$

$$R_c = cF_r U + (1-c)F_r \bar{u} + M_c + k_z$$

Where $(cF_r U)$ = costs of replacing the end items which will be condemned over the remaining program life

$(1-c)(F_r \bar{u})$ = costs of replacing component parts of the end item over the remaining program life

M_c = corrective maintenance costs over the remaining program life

But $M_c = \left[(1-c)M_{c_x} + (c)M_{c_y} \right] F_r$

Where M_{c_x} = average corrective maintenance costs per failure incurred for end items that are not condemned

M_{c_y} = average corrective maintenance costs per failure incurred for end items that are condemned

F_r = anticipated number of failures over the remaining program life

Thus, $R_c = F_r \left[(1-c)(M_{c_x} + \bar{u}) + c(U + M_{c_y}) \right] + k_z$

$$\begin{aligned} D_c - R_c &= F_r U - F_r \left[(1-c)(M_{c_x} + \bar{u}) + c(U + M_{c_y}) \right] - k_z \\ &= F_r \left[U - (1-c)(M_{c_x} + \bar{u}) - cU - cM_{c_y} \right] - k_z \\ &= F_r \left[(1-c)(U - M_{c_x} - \bar{u}) - cM_{c_y} \right] - k_z \end{aligned}$$

Therefore, a discard choice is justified when $R_c > D_c$ or when:

$$F_r \left[(1-c)(U - M_{c_x} - \bar{u}) - cM_{c_y} \right] < k_z$$

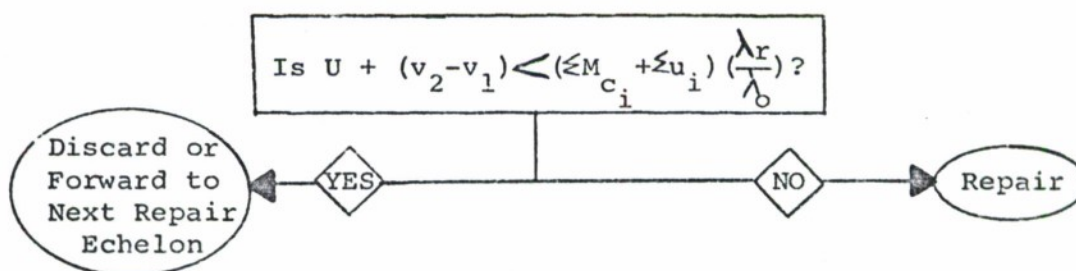
If the discard costs are greater than the repair costs, however, then an exhaustive economic analysis is required. Such analysis should consider the feasibility of redesigning the item. In such a case, one might be guided by the decision

process already discussed at the time of "Development of Design Specifications" and "Actual Design."

Repair Action

Screening Rule 1--Is the sum of the unit cost and the disposal value of the individual item less than the cost to repair that individual item?

Algebraic Expression:



Where U = unit cost of end item

v_1 = disposal costs

v_2 = reclamation value of end item if condemned

$\sum M_{c_i}$ = sum of the elements of corrective maintenance costs not yet incurred at the time of repair/discard screening

$\sum u_i$ = sum of the costs of the component parts necessary to make the repair

λ_r = failure rate of end items that have been repaired

λ_o = failure rate of new end items

Discussion--At this point, the repair/discard decision is made with regard to one individual item based primarily on the extent to which the item requires repair with due consideration for the cost of a new item and the disposal value of the failed item. If a repaired item is considered to be equally as reliable as a new one, then the ratio $(\frac{\lambda_r}{\lambda_o})$ should be given a value of one.

RELATED DECISIONS

Thus far, the repair/discard analysis has centered about the pure economic impacts resulting from a decision to repair or to discard at failure an item of equipment. During the course of analyzing the cost elements associated with repair or discard, it became apparent that there are often other factors which affect the quantitative values of the cost elements. In some cases, the outside influence eliminates any need to consider the alternative of repair and discard. In other cases, the outside influence is subject to manipulation or control. In either event, these outside influences represent additional considerations that should be evaluated simultaneously with the pure economics of repair versus discard.

These outside influences may best be analyzed as two separate types although one may actually be a product of the other. The first type may be termed "Technological and Military Constraints." Constraints result from related decisions which have been made prior to the time a repair/discard decision is considered. The second type may be termed "Related Decision Prerogatives." These influences refer to related decisions which at the time of a repair/discard analysis are still open to consideration or are subject to re-analysis and modification.

Once a related decision is made, it often results in imposing a technological or military constraint over any future repair/discard analysis. It is therefore important that such decisions be considered, if not determined, concurrently with the repair/discard decision in order to move toward an optimum balance of economy, effectiveness and readiness. If such a

goal is to be successfully pursued, it is essential that engineering, support, and military planning decisions which interact one upon the other be interdependently considered. This does not mean that all such decisions must be made at the same time. It does suggest, however, that once a decision has been made which interfaces with another decision, the result of the former be recognized and weighted appropriately.

Technological and Military Constraints

In some cases, the related decision which imposes a constraint over the repair/discard analysis is immediately apparent. In other cases, the constraint, though real enough in its effect on the repair/discard decision, is diffusely hidden in a network of related decisions which are difficult to isolate as the principal contributor to the constraint.

Constraints over the repair/discard decision may be classified into three categories--deployment planning, technological, and operational. Examples of such constraints are as follows:

Deployment Planning--The first type of constraint results from the deployment or usage plans which are established for the item under analysis or for the system under which the item being analyzed is a part. These types of constraints may result from such things as maximum down time requirements or mobility requirements. Such requirements may indirectly affect repair/discard economies through determining the item population, the number of operating hours per year, and the length of the program life.

In other cases, down time or mobility requirements may directly affect the repair/discard decision in that the requirement can only practically be met under a given repair or

discard policy. For example, an end item under consideration is a part of a unit where the mobility requirements are high and the weight and/or volume of the item makes it impractical to carry end items as spares. Under such conditions, the component parts of the item which are likely to fail must be carried and the item must be considered as reparable at the operational or maintenance field level even though it may be more economical to repair the item at the depot level, or to discard the item at failure. A similar type of constraint may be directly imposed by a decision to maintain a specific maintenance capability in the field, at the base or on board ship in order to prevent excessive down time.

Technological--Another type of constraint stems from the technological aspects surrounding the equipment under consideration. These constraints are brought about primarily from engineering decisions, but even these decisions may be attributable to early deployment planning. For example, extremely high reliability requirements would directly affect the repair/discard analysis by establishing a low failure rate. However, in order to meet high reliability requirements, the unit cost of the item may be significantly increased. Other technological constraints would include the physical characteristics of the item under consideration and the state-of-the-art of technology represented by the item. For example, most micro-electronic modules would have to be considered as discards simply because their physical characteristics preclude practical repair.

Operational Planning--The third category of constraints can be thought of as stemming from decisions regarding operational functions within the military departments, such as procurement and maintenance. Such constraints may affect

supplier lead time or depot turn-around time or the corrective maintenance cost. For example, if a decision has been made to procure an item from a single source, then the supplier lead time may have already been established by the terms of the contract and thus this lead time becomes a fixed factor in the repair/discard analysis.

It was stated earlier that where a constraint exists, the economic factor which is affected should be appropriately weighted in the repair/discard analysis. An example of this might be where the decision has been made to provide a specific maintenance capability at base. There are generally extreme fluctuations in the workload associated with base maintenance. One study indicated that an eight-man maintenance crew maintained 24 hours a day to take care of sporadic peak workloads only required all 8 men to be simultaneously engaged in maintenance operations one hour out of an entire month. In such cases where an item is being analyzed for repair/discard economic advantages, the maintenance capability in terms of personnel or equipment is available at no additional cost. This should be taken into account when estimating quantitative values of pertinent cost elements.

Related Decision Prerogatives

Depending on the point in the life cycle that the repair/discard analysis is undertaken, many of the related decisions which might result in technological or military constraints have not yet been made or may be subject to re-evaluation. Some of these decisions may not only have a strong impact on the repair/discard analysis, but may within themselves result in increased economies to the Government under either a repair or a discard policy.

Among the many decisions that are related directly or indirectly to the repair/discard decision, the following have been identified in our study as those which should, as a minimum, be considered in conjunction with a repair/discard analysis.

- Reliability vs. Unit Cost
- Standardization vs. Non-Standardization
- Type Procurement and Volume Purchased
- Contractor vs. Military Maintenance
- Preventive Maintenance vs. Corrective Maintenance
- Level of Maintenance
- Centralized Maintenance vs. De-Centralization

A brief description of the above decisions and their impact on the repair/discard decision is presented in the following sections of the report.

Reliability vs. Unit Cost--In the previous analysis of the economic cost elements pertinent to repair/discard, it was demonstrated that the failure rate and the unit cost of an item were among the most significant factors in the analysis at all points where the analysis might be undertaken. It should be recognized that in many cases, greater reliability can be achieved with an increase of unit cost. This decision prerogative is present during the design procurement stage but may be particularly pertinent at the time of actual design and during design review.

Standardization vs. Non-Standardization--The selection of a standard item of equipment over a non-standard has considerable impact on the repair/discard analysis. Many of the economies realized through the selection of a standard piece of equipment tend to minimize the cost associated with either

repair or discard policies. For example, the unit cost for a standard item is usually less than for a non-standard; the reliability is usually greater; procurement and maintenance costs are less by providing increased volume and allowing competition; and replacement costs are lower since interchangeability reduces pipeline requirements.

The item standardization prerogative has its greatest impact at the time of actual design. It is quite possible, however, under certain conditions to entertain the re-evaluation of a standardization decision at any time during the life cycle. For example, suppose a non-standard item is being reviewed for a repair/discard decision and it is found to be more economical to discard the item than to repair it. Further suppose that the same item was analyzed from a standardization point of view and it was found that the non-standard item could be substituted with a standard item. In such a case, greater benefits might result from the standardization action than would be possible from the repair/discard decision, although the decision to discard might have been correctly made.

Type Procurement and Volume Purchased--Procurement policies regarding competition or multi-year buys have a considerable impact on many of the cost elements associated with repair/discard, such as supplier qualification, inventory control, procurement costs, documentation costs, etc. Perhaps the greatest impact, however, is the effect of such policies on the unit cost of the item in question.

It has been demonstrated that the unit cost is among the most significant factors pertinent to the repair/discard analysis. While one would tend to think that unit cost of a specific item is somewhat stable once the item had been

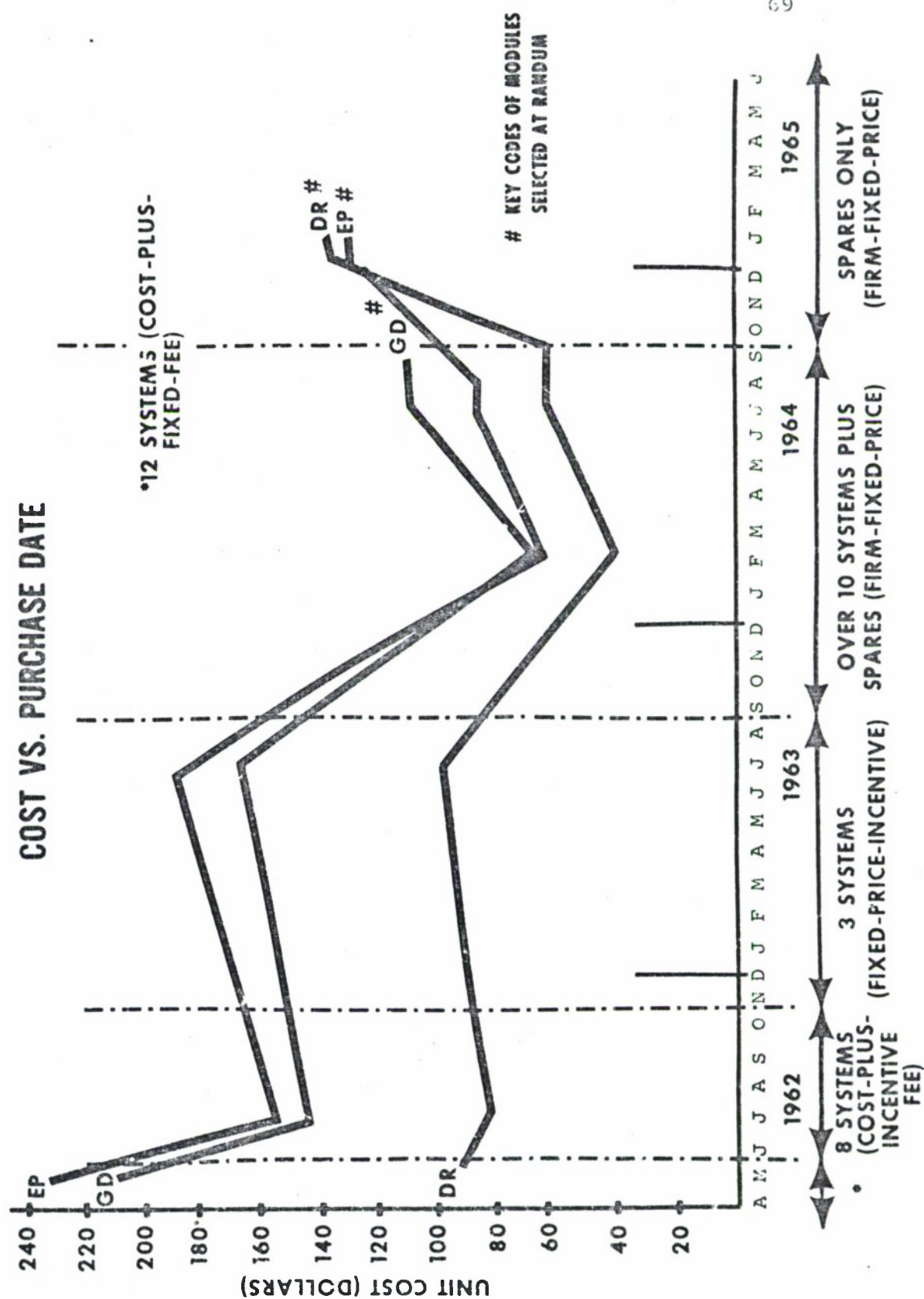
designed, our analysis indicated that the unit cost was often very sporadic and susceptible to fluctuations. For example, a case study undertaken on the MARK 84 Electronic Modules revealed that the average change in unit price for 151 electronic modules was 106% of the lower value. Thus, on the average, the high cost of all modules was more than double that of the low cost. Ninety per cent of the electronic modules examined were procured at different unit costs over a three-year period with the difference between high and low costs ranging up to 495% of the lower unit cost.

Further analysis indicated that there was no normal trend resulting in a decrease of unit cost. The unit cost is dependent among other things upon the volume of items being procured, and the type of contract. Figure 4 shows three electronic modules selected at random where the unit cost of various procurements is plotted over several years. The number of systems for which the electronic modules were procured and the type of contract under which they were procured are indicated across the bottom of the chart.

The point to be made in examining the fluctuations in the unit cost of these electronic modules is that the results of a repair/discard analysis based on the economic considerations above, would in many cases, turn out differently depending on the time at which the analysis was made and value of unit cost assumed. A further point to be made is that emphasis on the types of contract, the number of items to be procured and the decision to compete might have resulted in attaining the lower unit cost of the module. Exercising such decision prerogatives illustrates an attempt to control the situation or to control a particular cost element rather than reacting to current quantitative values.

TYPE III ANALOG MODULES

COST VS. PURCHASE DATE



Multi-year procurement decisions also affect the economic order quantities and hence can affect the procurement cost associated with any one specific item. Multi-year procurement decision prerogatives are generally present at any point of repair/discard analysis but have their greatest impact early in the program life cycle.

Contractor vs. Military Maintenance--The concept of contracting for the maintenance of military equipment in lieu of maintaining the equipment under a military-operated organization has been seriously considered on many major programs over the past several years. There are three facets of this approach.

The first facet consists of contracting directly for the repair and maintenance of specified equipment. This service may be contracted for with the manufacturer of the equipment or with an outside independent organization willing to perform such a service.

The second facet of the approach is to contract directly for the repair and maintenance coupled with a procurement contract. In other words, the contractor or the manufacturer agrees to repair and overhaul the equipment for a specified period of time for a specified price.

The third facet is a slight variation of the second in that the contractor or manufacturer of the equipment repairs or maintains the equipment but he is not directly paid or reimbursed for such repairs or maintenance. The cost of performing this operation is included in the unit price of the equipment. This latter approach has been referred to as a "Failure Free Warranty" by Lear Siegler Corporation.

Under the Lear Siegler approach, an item is guaranteed free of failure under certain specified conditions. Should

the item fail, it is returned to the manufacturer and is replaced free of charge. Under the Failure-Free-Warranty approach, the manufacturer may elect to repair or discard the failed item as he sees fit.

It should be noted that under the first two approaches, the decision to repair is implicit in the decision to contract for the repair or maintenance of the equipment. It should be further noted that such a decision implies that there is some advantage in the contractor performing the repair or maintenance rather than the military. Although such an advantage might very well be present with regard to a specific equipment or a specific contractor, we have found no basis for generalizing the advantage of contractor maintenance. On the contrary, our analysis of the repair/discard cost elements shows these elements to be highly vulnerable to military planning, related decisions which must be made by military personnel, and to various operational efficiencies, all of which tend to make the economics associated with each case different.

The decision to employ contractor maintenance in any form should not be used as a panacea for resolving the repair/discard decision and the many related decisions associated therewith. Contractor maintenance should rather be justified only as a means of seeking a more optimum state of maintenance operational efficiency.

Contractor maintenance may be considered by the Government at any point in the life cycle, but where it is justified, its greatest potential would seem to lie in the earlier points of the life cycle such as "Development of Design Specifications" or "Actual Design."

Preventive Maintenance vs. Corrective Maintenance--Sometimes there is an opportunity to make trade-offs with regard to the type and amount of preventive maintenance as contrasted with the type and amount of corrective maintenance. For example, one may anticipate the failures of certain component parts of an item and elect to remove and replace them before the actual failure occurs. This is the general concept behind equipment overhaul. The time between overhauls may be increased or decreased as a means of increasing or decreasing the amount of corrective maintenance. Such trade-offs are not always purely economic since they must often consider risk involved in down time.

Preventive versus corrective maintenance trade-offs are generally available at any point in the life cycle of the equipment. When these decisions are considered early, the design features of the equipment may be affected and hence the reliability or the unit cost may be affected. Since corrective maintenance stems primarily from random failures, and since it is often difficult to predict certain failure rates with a high degree of accuracy, consideration for preventive versus corrective maintenance after an item has been in service use can often result in realistic economic advantages due to increased knowledge concerning equipment failure rates, condemnation rates and repair costs. Commercial airlines have found it to be an economic necessity to continually make such trade-offs as the base of knowledge expands through increased flying hours.

Though at times increased frequency of preventive maintenance can increase the availability by assuring to a greater degree the reliability, it is also possible that inadequate

or poor preventive maintenance can induce failures to increase the failure rate and decrease both reliability and availability.¹

Level of Maintenance (e.g., Base versus Depot)--The level of maintenance refers to the echelon at which the repair or maintenance of the equipment will take place. The various alternative levels to be considered include operational personnel, field, base or shipboard, intermediate or ship tender, and depot or contractor. The economy of repair or discard often depends on the level at which repair is being considered and thus is an integral part of the repair/discard analysis. It may be found to be more economical to discard an item if the alternative to repair is considered only at a base facility. On the other hand, the same item may be more economical to repair than to discard if the repair takes place at a depot level. In either case, all of the cost elements involved are still pertinent, but the quantitative values may be considerably different. Moreover, there may be a significant difference in the technological and military constraints imposed at various levels of maintenance. The level of maintenance should be considered any time a repair/discard analysis is undertaken.

Centralized Maintenance Vs. De-Centralization--This type of consideration is similar to the one discussed earlier regarding level of maintenance (base versus depot). Consideration for centralized maintenance goes somewhat further than consideration for level of maintenance, however, in that it addresses the question of repairing all equipments of a similar type at one depot within a given military department or within all three military departments. For example, it was found that generators or generator sets were being overhauled or repaired

¹RAND Report, RM-3645-PR (Abridged) "Optimum Checkout Intervals and Launch Capability of Ballistic Missiles."

at almost every depot repair facility in the Army, Navy and Air Force. There is a great deal of similarity between generators or generator sets; the types of repairs required are similar; and the skills and equipment required to facilitate the repair are also quite similar. All of this suggests that there may be considerable economic advantage gained by centralizing the repair or overhaul of certain types of generators or generator sets which are used by all military departments.

There may be a number of different types of equipment with design, failure, and repair characteristics of such similarity as to warrant centralized maintenance. The advantage to be gained through such centralized maintenance would be to reduce the corrective maintenance cost through a large volume operation. It would appear that centralization of the maintenance or repair operation would often result in an economic advantage to repair collectively many types of items which when analyzed singularly are definitely discards. A case which would appropriately illustrate this point was related to us by a large commercial retailer who sold, among other major appliances, refrigerators on a broad national scale. The thermostat in the refrigerator--an item which costs under \$5.00--was historically discarded upon failure. As a result of the ingenuity of one of this commercial retailer's employees, a centralized repair operation was established for all thermostats resulting in considerable economic advantage.

It is suspected that there may be many common items used by the several military departments which would be more economically repaired at a central point. Moreover, many items which have historically been considered discards, might under a centralized maintenance operation, become candidates for repair with appreciable savings to the Government.

While centralized repair can be considered at design and initial source coding, certain limitations are inherently imposed due to the insulated environment in which most weapon and support systems are developed. A more advantageous point at which to consider centralized repair would be at the time of item review.

Related Decision Interfacing with Repair/Discard

It has already been stated that when a repair/discard analysis is made, not only should consideration be given to the technological and military constraints, but that it is often important to consider or reconsider alternatives for certain related decisions. This process may be thought of as decision interfacing--interfacing the constraints resulting from decisions already made and determining the impact on repair/discard by exercising related decision prerogatives. Figure 5, "Hypothetical Illustration of Repair/Discard and Related Decision Interfacing," will aid in illustrating the effect of decision interfacing on the outcome of a repair/discard analysis.

Figure 5 depicts three separate repair/discard analyses with respect to one hypothetical piece of equipment. The first analysis considers all of the major economic elements and hypothetical quantitative values have been assigned to each cost element under both a repair and discard choice. We will use the corrective maintenance cost as the subject for illustrating decision interfacing.

Assume that in the first analysis the corrective maintenance cost was calculated by determining the number of man hours required to make the necessary repairs and that these

HYPOTHETICAL ILLUSTRATION OF REPAIR/DISCARD AND RELATED DECISION INTERFACING

★ THESE COSTS ARE CONSIDERED NEGLIGIBLE.

★ THESE COSTS ARE CONSIDERED NEGLIGIBLE.

TECHNOLOGICAL AND MILITARY CONSTRAINTS

RELATED DECISION PREROGATIVES

ECONOMIC ELEMENTS	QUANTITATIVE VALUE WITHOUT REGARD TO TECHNOLOGICAL AND MILITARY CONSTRAINTS		QUALITATIVE OR QUANTITATIVE MODIFICATIONS REGARDING TECHNOLOGICAL & MILITARY CONSTRAINTS		QUALITATIVE OR QUANTITATIVE MODIFICATIONS RESULTING FROM RELATED DECISIONS	
	REPAIR	DISCARD	REPAIR	DISCARD	REPAIR	DISCARD
DESIGN COST	20,000	20,000	20,000	20,000	20,000	20,000
INITIAL END ITEM PROCUREMENT	1,500,000	1,500,000	1,500,000	1,500,000	1,500,000	1,500,000
REPLACEMENT COST	100,000	800,000	100,000	800,000	100,000	800,000
PREVENTIVE MAINTENANCE & OPERATION	16,000	16,000	16,000	16,000	16,000	16,000
CORRECTIVE MAINTENANCE OPERATION	750,000	★	550,000	★	150,000	★
SUPPLY OPERATION	23,000	★	23,000	★	23,000	★
SPEC. CORR. MAINT. TOOLS & TEST EQUIP	15,000	★	15,000	★	15,000	★
DOCUMENTATION	35,000	★	35,000	★	35,000	★
TRAINING	60,000	★	60,000	★	60,000	★
DISPOSAL VALUE	★	30,000	★	30,000	★	30,000
TOTAL	2,519,000	2,366,000	2,319,000	2,366,000	2,019,000	2,366,000
POLICY SELECTED (X) ECON. ADVANTAGES	\$153,000	X	X	\$47,000	X	\$345,000

hours were extended by multiplying a weighted labor rate for such maintenance skills as were required. Further assume that in calculating the corrective maintenance cost, no particular consideration was given to the specific environment in which the repair operation would take place. It will be noted that in this first analysis the cost to repair exceeds the cost to discard by \$153,000. Thus, the decision would be made on a purely economic basis to discard.

The second analysis on Figure 5 takes into consideration the results of decisions already made and falls under the heading "Technological and Military Constraints." Assume that one such decision was to maintain a certain maintenance capability at the bases at which the item under analysis would be used. Further assume that the fluctuations in workload at these bases allowed ample opportunity to make certain required repairs at no additional cost to the Government. Let us assume that after identifying such repairs and determining the original corrective maintenance cost attributed thereto, we find that the total corrective maintenance cost is reduced by \$200,000. It will be noted that the second analysis results in the cost to discard exceeding the cost to repair by \$47,000, hence, the decision to repair would be the appropriate decision under the conditions cited.

Suppose that further analysis is undertaken and it is found that the corrective maintenance cost can be significantly reduced by increasing preventive maintenance. In this case, Figure 5 shows under the heading "Related Decision Prerogatives," the corrective maintenance cost decreased and the preventive maintenance cost increased--resulting in a net decrease in the cost to repair. Thus, the decision in the third analysis would be to repair, but the economic advantage has now increased to \$345,000.

It should be recognized that a repair/discard analysis without regard to the technological or military constraints associated with the item under analysis is unrealistic and may often lead to an erroneous decision. It should be further recognized that failure to consider related decision prerogatives available at the time of analysis may often result in considerably less than optimum economy in support of the equipment in question.

REPAIR/DISCARD DECISION GUIDELINES

There are five general guidelines suggested that should be applied at all points in the life cycle where the repair/discard decision is considered. These are:

- Presume that the item will be repaired unless a discard decision is justified.
- Direct the repair/discard analysis initially toward the highest levels of assembly and proceed to the next lower levels only until a discard decision is justified.
- Apply screening rules before subjecting items to an exhaustive economic analysis.
- Identify and analyze significant related decisions prior to the repair/discard analysis in order to (a) determine technological and military constraints over the repair/discard decision, and (b) determine what decision prerogatives may be exercised.
- Conduct the repair/discard analysis with appropriate consideration and weight given to the identified

technological and military constraints, but beyond that, make every effort to control the repair/discard decision by exercising appropriate related decision prerogatives which seek an optimum balance of support economy, military effectiveness and operational readiness among the related decisions identified.

Figure 6, "Decision Network for Related Decision Interfacing," illustrates the framework in which the repair/discard decision analysis should take place in accordance with the major guidelines stated above. The initial step at any point in the life cycle where the repair/discard decision is considered is to identify those related decision prerogatives which are to be concurrently analyzed before any one specific decision is made. This step in the process is depicted in Figure 6 as the rectangle on the right entitled "Related Decision Prerogatives."

Once all of the decisions which significantly interact one upon the other are identified, an integrated decision analysis is undertaken. It is not suggested that this integrated decision analysis results necessarily in reaching a firm decision for all decision prerogatives initially identified. It is rather intended that this step of the process would primarily address the question "are there decisions which should now be made or have already been made which result in technological or military constraints over the design or support characteristics of the equipment"? If such decisions are made, then the resultant technological and military constraints should be identified and the decision prerogatives which initially existed should be eliminated.

DECISION NETWORK FOR RELATED DECISION INTERFACING

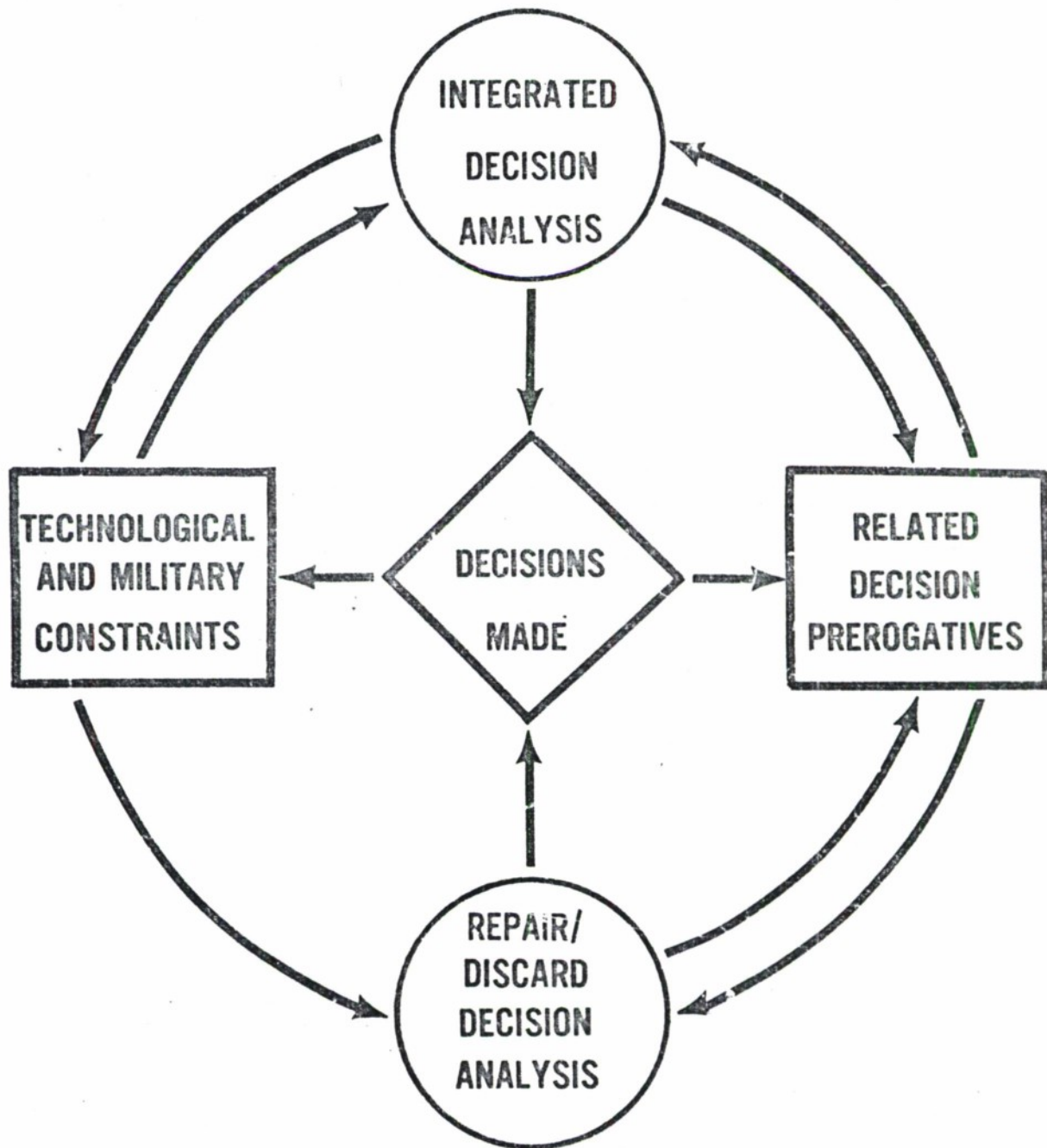


FIGURE 6

The integrated decision analysis is cyclic in nature as indicated by the arrows on Figure 6--that is, many alternatives may be considered before the actual decision is made. Where appropriate, simulation techniques might be used in the integrated decision analysis to see the over-all effect of various combinations of decision prerogatives. In any event, once any of the related decisions are made, any technological or military constraints resulting therefrom should be clearly identified and appropriately considered in the repair/discard decision analysis.

Once the repair/discard decision is made, this decision might very well become or result in a technological or military constraint on some of the other related decision prerogatives initially identified.

It should be noted that the integrated decision analyses depicted in Figure 6 are equally applicable from the viewpoint of any of the individual related decisions as they are from the viewpoint of the repair/discard decision. Thus, the decision process depicted here is actually a means of concurrently examining any group of dependent interrelated decisions. The key to the success of this approach is in the initial identification of those related decisions which significantly interact one upon the other and the adoption of a policy which requires integrated decision analysis.

Figure 7, "Typical Repair/Discard Decision Process," schematically illustrates a typical application of the repair/discard decision guidelines suggested at any point in the life cycle where the repair/discard decision is considered.

We believe that the integrated decision analysis approach can contribute significantly toward improving integrated logistics support and in meeting the goals set forth in DoD Directive

4100.35 in addition to improving the repair/discard decisions. This approach has the decisive advantage of limiting the variety of logistics support considerations to a select few which are significant, the interrelationships are definitive, and the decisions are manageable.

TYPICAL REPAIR/DISCARD DECISION PROCESS

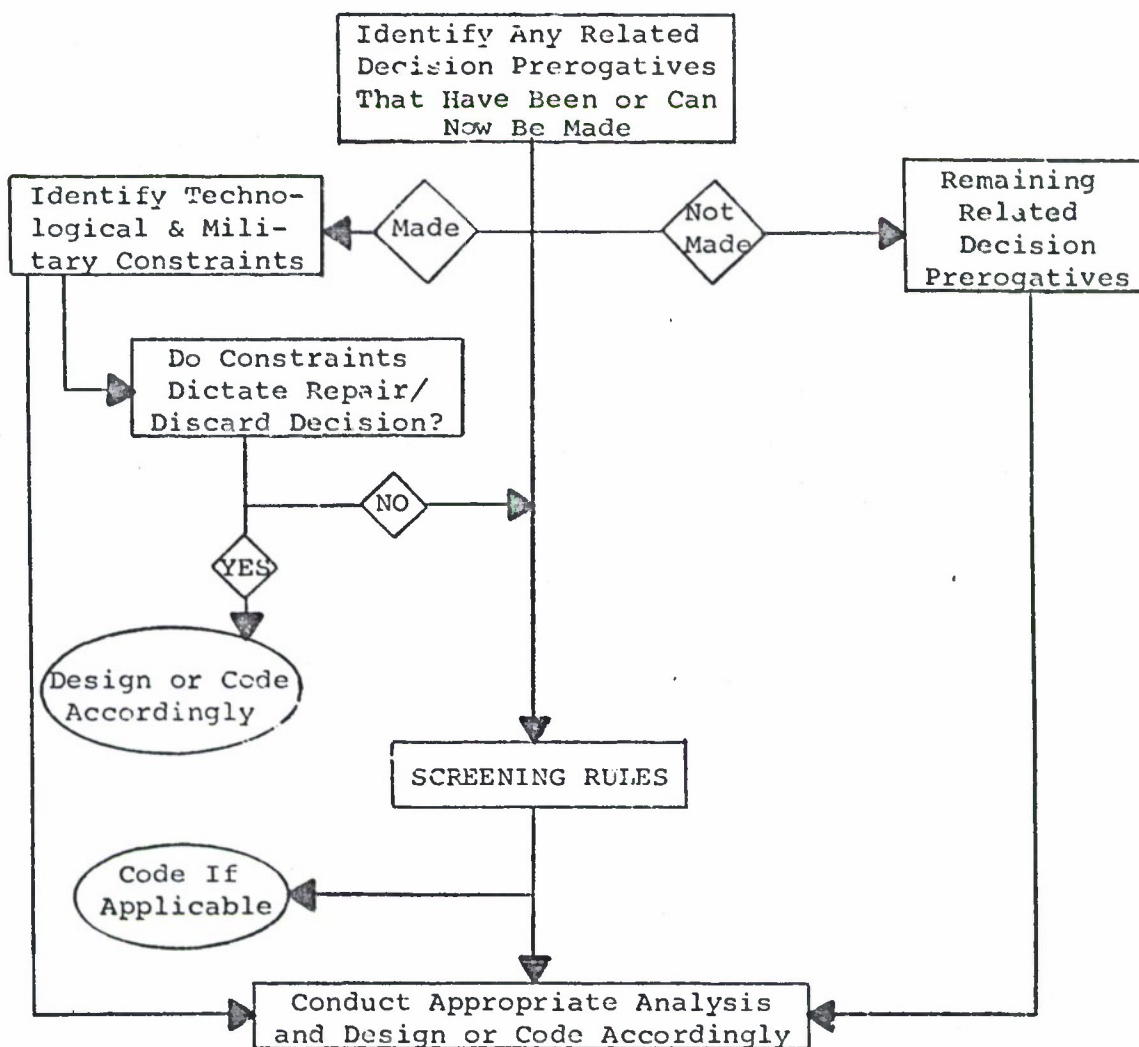


Figure 7

III. CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

A great number of detailed conclusions have been drawn during the course of analyzing the repair/discard decision process and the impact of such decisions on military equipment readiness and support posture. Many of these conclusions have, in fact, influenced the direction and scope of the study as well as the criteria developed to improve the decision process. Many detailed conclusions have been stated throughout the report as they occur in the study analysis described. In the interest of brevity and avoiding repetition, we will not attempt to restate such detailed conclusions here, but rather to present as succinctly as possible the major conclusions of the study as they relate to two principal areas of requirements for improving the decision process. The two principal areas are:

- Economic Criteria
- Decision Integration

Conclusion No. 1: Economic Criteria

Items entering or entered in the military supply system should be subjected to a repair/discard decision analysis using a screening process which rapidly and at nominal cost either indicates the decision or defers the decision to a point of greater vantage by initially favoring repair, and calls for an exhaustive economic analysis only when significant benefit appears likely.

Since it is generally impractical to repair an item once it has been classified as a discard item, every item should be considered repairable until a discard classification has been justified. It is also desirable to justify the discard classification at the highest practical assembly level.

The economic elements associated with a repair/discard decision vary according to the point in the life cycle where the analysis is undertaken. Moreover, quantitative values for these elements vary significantly at any given point depending on technological factors, characteristics of the item, and the application environment. Use of one simple set of economic criteria at all points would be unsound. It would also be impractical to conduct an exhaustive economic analysis of each item entering the military supply system, because the cost of making the analysis would often offset the economic advantage resulting from the proper repair/discard decision. Therefore, a screening process should be introduced. This process should be tailored to specific points in the life cycle and should permit rapid choice at nominal cost when the economic potential is small or when the answer is readily obtainable.

Establishment of four economic constants with respect to categories of similar items will suffice for initial implementation of the screening process at the time of "Initial Source Coding" and "Coding/Design Review." These constants are:

- minimum costs to enter an item into the repair cycle (k_x)
- minimum costs to introduce a new item into the supply system (k_y)
- minimum approximation of documentation, training, and supply costs (k_z)
- minimum remaining program life needed in order to justify coding or design change (x)

Conclusion No. 2: Decision Integration

To achieve a more optimum balance of economic support without sacrificing military effectiveness or operational readiness, appropriate repair/discard decisions must be integrated with certain other related decisions.

Significant related decisions should be considered whenever a repair/discard analysis is undertaken. The results of decisions already made constitute constraints and often dictate the repair/discard decision. Decisions not yet made or susceptible to change constitute prerogatives which may be exercised.

Following are some decisions which are related to and should where appropriate be considered in conjunction with the repair/discard choice:

1. Reliability vs. Unit Cost
2. Standardization vs. Non-Standardization
3. Type Procurement and Volume Purchased
4. Contractor vs. Military Maintenance
5. Preventive vs. Corrective Maintenance
6. Level of Maintenance (i.e., Base vs. Depot)
7. Centralized vs. De-Centralized Maintenance

It is believed that such areas of decisions as cited above can with relative ease be reduced to appropriate decision logic networks which will enable them to be collectively manageable with the repair/discard decision under an integrated decision analysis approach. There are many other related decisions which also affect repair/discard and the aforementioned decision areas, but which may be considerably more difficult to reduce to a definitive decision logic network. Such decisions will often deal with performance and design characteristics of the equipment, intended

uses, and readiness requirements. Nevertheless, these types of decisions should be taken under consideration and integrated where appropriate. In any event, the results of such decisions should be clearly identified as technological or military constraints over the repair/discard choice where such constraints exist. The identification of constraints draws management attention to the decisions which produced the constraints and may often suggest a re-evaluation of such decisions.

The related decisions could have more impact on cost, effectiveness, or readiness than the repair/discard decision itself. Thus, a pure economic analysis of repair/discard costs, including consideration of constraints, can lead to a suboptimum conclusion. It is better to analyze the repair/discard choice in light of the remaining decision prerogatives in an attempt to control the situation rather than simply reacting to it.

Although it is recognized that the broad spectrum of integrated logistics support falls outside the initially intended scope of this study, it is appropriate, we believe, to emphasize the necessity to improve the techniques for achieving the goals of integrated logistics support concurrently and in conjunction with improving the ability to make repair/discard decisions.

We believe that the approach described in this report of identifying and selecting a few significant interrelated decisions which are clearly definable and subjecting them to an integrated decision analysis represents an improved technique and will contribute significantly to the objectives of DoD Directive 4100.35, and in fact, is the key to achieving successful integrated logistics support.

RECOMMENDATIONS

The analysis of the repair/discard decision process and the conclusions that have followed clearly indicate that improvement in reaching repair/discard decisions and reaping the benefits achievable through integrated decision analysis involves many different functional areas within the Defense establishment. The analysis and conclusions further indicate that concurrent and uniform actions are required within the various functional areas affected. Therefore, the recommendations presented in this report are aimed at achieving the broadest possible benefits to the Government in accordance with the findings and conclusions of this study and are directed to the Assistant Secretary of Defense (Installations and Logistics).

Recommendation No. 1--Uniform Repair/Discard Criteria

It is recommended that uniform procedures for making repair/discard decisions be established by System Program Managers, Inventory Managers and Maintenance Depot Managers using the LMI report as a guide.

The establishment and use of uniform procedures for making repair/discard decisions will, it is believed, contribute significantly to improved support effectiveness and economy in several ways. First, the procedures and criteria for decisions themselves can provide the basis for a less costly and more effective decision process. Second, application of the procedures at significant points in the life cycle can provide a more effective management discipline over the decision process than is now the case. Third, the use of uniform procedures within the military departments based on a common set of criteria can provide better

communication among the departments and between points in the life cycle where repair/discard decisions are considered, and can provide the basis for the development of quantitative cost factors of increased sensitivity. Fourth, the use of uniform procedures will allow better management visibility of policies and practices which affect equipment readiness and support economies. Finally, the use of uniform procedures will provide a basis for identifying potential resultant economies through centralization of supply or repair activities.

It is suggested that the uniform procedures initially adopt the decision processes including the screening rules developed in this study. The screening rules may be refined for greater effectiveness as increased data concerning repair and support of common classes of equipment becomes available.

Recommendation No. 2--Contractor Requirements in Future System Development

It is recommended that the application of repair/discard decision procedures, including consideration for related decisions, be required of contractors in the design and development of future major programs and that the decision network and management plan for making such decisions be made a requirement in Contract Definition.

In order to achieve the benefits that may result from early repair/discard and other related decisions, these decisions should be considered during the design phase. Certain guidelines, including economic criteria and decision networks have been suggested in this report. The repair/discard decision process might be outlined in a detailed specification or in a DoD Standard and invoked on the contractor as a contract requirement. However,

we believe that such rigid control would be premature and, in fact, may not be necessary. It is believed, however, that increased attention to the question of repair versus discard during design is required and that certain trade-offs should be considered by the contractor based on economic criteria furnished by the Government.

Recommendation No. 3: Contractor Participation in Current Systems

It is recommended that appropriate steps be taken to encourage DoD contractors with current Development or Production contracts to utilize the guidelines for making repair/discard decisions presented in this report as a means of broadening the scope of their Value Engineering Programs.

Implementation of Recommendations No. 1 and 2 will contribute toward improving the repair/discard decisions with regard to appropriate coding of assemblies and items already in the military supply system and to the design decisions of future assemblies or items entering the system. There remains, however, another facet of repair/discard which requires increased attention. This facet deals with the improved economics or readiness posture achievable through the re-design of assemblies or items specifically as a reparable or non-reparable when it is appropriate to do so. In essence, this is Value Engineering prompted primarily through consideration for improved support.

The Armed Services Procurement Regulations on Value Engineering (Section I, Part 17) provide for a formal VE program to be required in contracts over \$1,000,000 and for VE profit-sharing arrangements to be allowed in contracts over \$100,000. Thus, most existing contracts either require or encourage Value Engineering.

It is believed that significant contributions can be realized by encouraging contractors to improve their Value Engineering programs through additional emphasis on improved support.

Two approaches are suggested to implement this recommendation. First, the benefits achievable by considering repair/discard criteria in conjunction with Value Engineering could be emphasized by appropriate OSD authority and communicated to Defense contractors through normal channels such as Defense circulars, news media, or direct mail. Such action would, it is believed, result in immediate response by industry. The second approach is to develop a supplement to the Department of Defense Value Engineering Handbook (H-111) which will describe the repair/discard decision process as it might be incorporated into a Value Engineering Program.

APPENDIX I

BIBLIOGRAPHY OF BACKGROUND MATERIAL

FOR LMI REPAIR VS. DISCARD STUDY

1. A Cost Comparison Technique for Expendability-Repair Decisions, by Major Virgil H. Rizer, Major William A. Brown, and Major LeGrand W. Burt, School of Logistics, Air Force Institute of Technology, Wright-Patterson Air Force Base, Ohio; 1 June 1958.
2. A Study of Procurement Costs at the Ships Parts Control Center, (First Progress Report), prepared for Research & Development Division, BuSANDA; 15 September 1960; Contract No. Nonr-2860(00); Dunlap & Associates, Inc., Stamford, Connecticut.
3. A Study of Procurement Costs at the Ships Parts Control Center, (Second Progress Report), prepared for Advanced Logistics Research Division of BuSANDA; 31 December 1960; Contract No. Nonr-2860(00); Dunlap & Associates, Inc., Stamford, Connecticut.
4. Alternate Methods of Reducing the Ultimate Costs to the Government of Acquiring and Maintaining Items in the Inventory; by Lt. Colonel Jack P. Ancker, USA and Captain Bruce S. Benefield, USAF (A student thesis); School of Systems & Logistics, Air Force Institute of Technology, Wright-Patterson Air Force Base, Ohio; SLSR-10-64; June, 1964.
5. An Aggregate Base Stockage Policy for Recoverable Spare Parts, by G. J. Feeney, J. W. Peterson, and C. C. Sherbrooke, prepared for USAF (RAND); Memorandum RM-3644-PR; June, 1963.
6. An Evaluation of Module Replacement and Disposal at Failure for Maintenance of Ground Electronic Equipment, by John J. Andrea, Collins Radio Company for Rome Air Development Center, RADC TR-60-5; Contract No. AF 30 (602)1877; Defense Documentation Center No. AD 232-917.

7. An Examination of the Marine Corps Replacement and Evacuation Program, by H. B. Wilder, Jr.; prepared for Office of Naval Research, Contract Nonr 2332(00); Stanford Research Institute, April, 1962.
8. Criteria for Discard-at-Failure Maintenance, by Eugene G. Wrieden; (prepared for Rome Air Development Center), March, 1963; IBM No. 63-928-7, Contract No. AF 30(602)2681; Defense Documentation Center No. 405779.
9. Economic Decision Criteria for Repair Versus Throwaway Maintenance, by O. E. Davis (prepared for BuSHIPS), Contract No. 89362; Vitro Laboratories, Silver Spring, Maryland; Defense Documentation Center No. 455102.
10. Economics of the Trade-off Among Reliability, Maintainability and Supply, by A. S. Goldman, H. P. Kramer, W. H. Root and T. M. Whiting; RM 62TMP-42; 30 June 1962; TEMPO, General Electric Company, Santa Barbara, California.
11. Ground Electronic Equipment Support Cost vs. Reliability and Maintainability, by R. L. McLaughlin and H. D. Voegtlen, Government Service Department, RCA; Cherry Hill, New Jersey.
12. Initial Provisioning, prepared for Deputy Chief of Staff/Logistics, USA; August, 1963, Federal Systems Division, IBM, Rockville, Maryland.
13. Maintainability--A Major Element of System Effectiveness, by A. S. Goldman and T. B. Slattery; General Electric TEMPO; John Wiley & Sons, Inc.; New York, 1964.
14. Maintainability Engineering, prepared for Rome Air Development Center by Government Services, RCA Service Company, Cherry Hill, New Jersey; Contract AF 30(602)2057; 5 February 1963; RADC TDR 63-85, Vol. II.
15. Optimal Decision Rules for the Procurement, Repair, or Disposal of Spare Parts, by E. S. Phelps, prepared for USAF (RAND), Memorandum RM-2920-PR, May, 1962.

16. Preliminary Analyses of Repair-Discard Maintenance Alternatives and Checkout Frequency for the Polaris Guidance Capsule, by William B. Thompson, General Electric TEMPO, Santa Barbara, California; RM 60TMP-13; 29 February, 1960.
17. Preliminary Methods for the Evaluation of the Effects of Spares Allocations on FEM Unreadiness, by W. J. Howard and H. H. Peterson; General Electric TEMPO, Santa Barbara, California; RM 62TMP-52; 1 September 1962.
18. Report on Determination of Need for Breakdown and Provisioning of Vendor Repairable Items (VRI), prepared for the Department of Defense by VRI Panels of the Spare Parts Committees of the Aerospace Industries Association of America, Inc., Electronic Industries Association; June 1960.
19. Support Requirements for Opportunistic Replacement and Inspection Policies, by J. J. McCall; prepared for USAF (RAND); Memorandum RM-3369-FR; December, 1962, Santa Monica, California.

APPENDIX II

DERIVATION OF END ITEM REPLACEMENT COST

Let E = end item replacement cost for the life of the program in which the end item is used

The replacement cost E consists of two major elements--the cost required to initially fill the supply pipeline with end items and the cost of replacing end items when condemned from service use.

$$\text{Thus,} \quad E = [E_p + E_c] U$$

Where E_p = number of end items required to initially fill the supply pipeline

E_c = number of end items that are condemned from service use over the life of the program

U = average unit cost of the end item

Let c = condemnation rate or the ratio of all items over the program life that are condemned to the total number item failures over the program life

Now, if we assume that c is constant over the program life, the initial supply pipeline requirements can be expressed as:

$$E_p = f(c)L_s + f(1-c)L_d$$

Where f = number of failures per year

L_s = supplier lead time in years

L_d = lead time to and from repair depot in years

The number of end items condemned over the program life may be expressed as:

$$E_c = f(c)P$$

Where P = program life in years

Thus,

$$E = [f(c)L_s + f(1-c)L_d + f(c)P] \quad \text{fU}$$

$$E = [c L_s + (1-c)L_d + cP] \quad \text{fU}$$

$$E = [c(L_s - L_d + P) + L_d] \quad \text{fU}$$

APPENDIX III

CORRECTING FOR DEGRADATION (AGGRADATION) OF ITEM RELIABILITY RESULTING FROM REPAIR

The failure rate (λ) used in the mathematical model presented in the report should, where appropriate, be corrected to reflect an increase or decrease in item reliability resulting from initial repair of the item. A method for making such a correction is developed as follows: The method presented considers only a major difference in failure rate resulting from the first repair of any given item, and does not include those cases where the failure rate becomes progressively worse or better with each subsequent repair.

Let F = total number of item failures over the program life

So that,

$$F = F_0 + F_r$$

Where F_0 = number of failures resulting from a new item with a failure rate of λ_0

F_r = number of failures resulting from a repaired item with a failure rate of λ_r

$$\text{Now, } F_0 = \lambda_0 h p P_1$$

Where λ_0 = average failure rate of a new item in failures per operating hour

h = average number of operating hours per year for each item in the population

p = item population

P_1 = that portion of total program life P required for all original items (new) in population to fail once

Thus,

$$F_o = p = \lambda_o h p P_1$$

or
$$P_1 = \frac{1}{\lambda_o h}$$

Now,
$$F_r = \lambda_r h p (P - P_1)$$

So that,

$$F = F_o + F_r$$

$$\lambda p h P = p + \lambda_r h p (P - P_1)$$

$$\lambda = \frac{p}{p h P} + \frac{\lambda_r h p (P - \frac{1}{\lambda_o h})}{p h P}$$

$$\lambda = \frac{1}{h P} + \frac{\lambda_r (P - \frac{1}{\lambda_o h})}{P}$$

$$\lambda = \frac{1 + \lambda_r h P - \frac{\lambda_r}{\lambda_o}}{h P}$$

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