LIFE CYCLE COSTING IN

EQUIPMENT PROCUREMENT

TASK 4C-5

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LOGISTICS MANAGEMENT INSTITUTE
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April, 1965

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"Award shall be made. . . to the respon-
sible bidder whose bid. . . will be most
advantageous to the United States, price
and other factors considered."[1]

From the enactment in 1861 of what subsequently became known as
Section 3709 of the Revised Statutes, through two world wars and
subsequently under the Armed Services Procurement Act and its
codification, the word "price" has received virtually the only
consideration in awarding contracts placed by formal advertising.
The phrase "other factors," for all practical purposes, is being
ignored. Reliance upon its presence in the U. S. Code as the
basis for award to other than the low bidder is rare. By an
overwhelming proportion, awards of contracts under formal ad-
vertising are made to bidders submitting the lowest prices.

Although the Code is silent regarding awards of negotiated
contracts, customarily the DoD follows the precedent of Section
2305(c) of Title 10 and awards to companies submitting the low-
est quotations. There are undoubtedly many reasons for this,
not the least of which is industry's practice of protesting to
members of Congress and the General Accounting Office[2] whenever
attempts are made to award on any other basis. Such protests
tend to interfere with the orderly process of procurement and
frequently produce serious delays in making awards.

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[1] Section 2305(c), Title 10, United States Code.

[2] This, in spite of the fact that the Comptroller General
seldom intervenes in Contracting Officers' selection of con-
tractors in negotiated procurement.

As will be noted in this report, many persons within the DoD have become concerned that the traditional policy of awarding contracts on the basis of price alone may not always be in the best interest of the Government. Specifically, the effect that competition, with its potential for changing suppliers, may have on life cycle costs is thought to require study. Thus, the issuance by the Assistant Secretary of Defense (Installations and Logistics) of Task Orders 4C-2 and 4C-5, to which this report is responsive.

This study is devoted to an investigation of the influence that changes in suppliers, resulting from negotiated competition, may have on logistics costs, and how this influence might appropriately be considered in making contract awards.[1]

Since the study is focused on the competitive procurement decision, all collateral investigation has been confined to those equipment procurements normally susceptible to competition. As a consequence, research and development is excluded as are major systems which are seldom procured competitively. Likewise, procurements having insignificant logistics cost implications (e.g., services, subsistence, fuels and lubricants) are excluded from the study.

While this report is furnished to the Assistant Secretary of Defense (I&L), in answer to Task Orders 4C-2 and 4C-5, and to the Deputy Assistant Secretary of Defense for Procurement, under whose cognizance the project has been performed, it is also intended for all those who might be charged with the responsibility to assist in carrying out the recommendations presented. This group includes Contracting Officers and other

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[1] As will be seen, this report recommends that consideration of logistics costs be concentrated, for the time being, on negotiated procurement.

procurement personnel who participate in assessing the economic
feasibility of negotiated competition, preparing Requests for
Proposals, and evaluating proposals received. In addition, it
embraces other logistics personnel (representing such functions
as Comptroller, Engineering, Maintenance, Supply, and Training)
who might be called upon to assist in performing logistics cost
analyses for the purpose of awarding contracts on the basis of
lowest life cycle cost. Finally, it takes in those who may com-
prise the proposed OSD Ad Hoc Committee under whose auspices
tests discussed in the Recommendations would be carried out.

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

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I. INTRODUCTION

Pursuant to Task Order 4C-2, LMI undertook a reconnaissance study beginning in November 1963 to assess "the area of life cycle (total) costing as related to the economics of competitive procurement." Following the reconnaissance, Task 4C-5, authorized on 17 March 64, was undertaken by LMI. Its objectives are to:

1. identify and study major categories of cost that are incurred during the useful life of equipments;

2. establish the relative importance of these categories with respect to life cycle costs, by equipment types;

3. develop methods for measuring and forecasting these costs when procurement of a specific equipment type is being planned, and guidelines for evaluating these costs in the process of reaching a procurement decision;

4. develop guides for using alternative approaches to minimize life cycle cost (e.g., multi-year procurement) when such approaches are more appropriate than the techniques mentioned in Item (3) above; and

5. conduct a test program, on a sampling basis, to establish the feasibility of use in actual procurements of methods developed in Item (3) above.

Early in the study it became evident that the "alternative approaches" contemplated by objective (4) were not truly alternatives to life cycle costing, but rather techniques which can be employed with or without life cycle costing. Guidelines for their application have been and are the subjects of separate projects. Therefore, they were not included in the remainder of the study. Detailed Specifications, Plans and Drawings and Failure Free Warranty were, however, identified as "alternative approaches." They will be discussed in Part G of Section III.

As the project progressed, it became increasingly clear that an effective test program (in response to objective (5)) would necessarily involve following several procurements in detail, and on a real-time basis, from RFP preparation through contract award. Such testing was not possible within the time span of the task. In addition, because so much of the effort would most appropriately be carried out by personnel of the military departments, it was concluded that the test program should be organized as a separate (second-stage) study. The Recommendations in Section IV of this report cover this subject.

Objectives (1), (2), and (3) are addressed by Parts B, C, and D, respectively, of Section III.

Relationship of Life Cycle Costing to Other Studies

In the truest sense, the life cycle cost of military equipment is the total cost incurred by the Government from the moment the investigation of its generating idea elicits manpower usage within or without the Government until every piece of the equipment is eliminated from the military logistics system. The term thus embraces all costs associated with feasibility studies, research, development, design and production, and all

support, training and operating costs generated by acquisition
of the equipment. Over the last several years, numerous studies
of life cycle costing have been initiated. LMI has conducted or
currently is conducting studies relating to several specific
phases of this subject. Some of these are:

- Change Management (Control of Engineering and Design Changes)

- Cost/Effectiveness Support Plans for Major Weapon Systems

- Measurement Systems for DoD Warehousing and Stores Functions

- Optimum Mix of Military-Defense Industry Support Capability

- Recoverable vs. Non-Recoverable (Repair vs. Discard)

- Reduction in Overhaul and Repair Turn-Around Time (Navy)

- Ships On-Board Repair Parts Outfitting

- Standardization

All these study efforts have been or are being devoted to im-
proving methods and procedures for controlling and, in most in-
stances, reducing life cycle costs of military equipment. They
are all aimed at optimizing the relationship between operational
effectiveness and life cycle costs. For instance, the Study of
the DoD Standardization Program had as its objectives, the "im-
provement of effectiveness of logistics support and of opera-
tional readiness, and conservation of facilities and resources."[1]

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[1] Briefing on LMI Study of the DoD Standardization Program
to the DoD Council for Technical Data and Standardization Policy
on 7 May 1964 at Aberdeen Proving Ground.

The Study of Ships On-Board Repair Parts Outfitting has, as its objective, the reduction of 'any present excess inventory and minimizing of possibilities of future inventory excesses, thus reducing costs without sacrificing support capability."[1] The task order expresses the hope that the "ultimate result /of the study/ may be to improve ship on-board support effectiveness at reduced outfitting costs."[2]

Another LMI task calls for development of improved decision guidelines for determining the "optimum mix of military/defense industry capabilities for depot level support of major project-managed weapons and equipment. It shall include an attempt to develop improved criteria for establishing the most cost-effective timing of the phase-over of support from industry to the DoD. . ."[3]

A major common characteristic of all these studies is a concern with life cycle costs. A common requirement is a need to identify and quantify life cycle costs. It is in the specific uses of cost information that life cycle cost studies tend to digress and deviate from each other.

Project 4C-5 shares this characteristic with all other studies of life cycle costing. Since it also has its own peculiar needs for cost information, it tends to deviate from other studies and to make distinctions among the various categories of cost in order to meet those needs.

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[1] LMI Task 65-13, Study of Ships On-Board Repair Parts Outfitting and Revision of Present Associated Supply Aids, November 11, 1964.

[2] Ibid.

[3] LMI Task 1H, Optimum Mix of Military/Defense Industry Support Capability, 23 May 1964.

Relationship of Life Cycle Costing to the Competitive Procurement Decision

Among the major influences contributing to changes in life cycle costs are changes in the physical and functional characteristics of equipment which take place not only during equipment design, but also after initial design has been established. Changes in equipment arise from numerous sources and for many reasons. Some changes are controlled, resulting from Government direction or approval, e.g., a directed change in operational characteristics by the Government or a formal engineering change proposal by the contractor to correct a design deficiency. Other changes occur in an uncontrolled manner as a result of changes in suppliers.

The formal, carefully controlled change, typified by the ECP procedure, and the effect of such change on life cycle costs, is the subject of another LMI study.[1] Project 4C-5, on the other hand, concerns itself with those changes in life cycle costs which are by-products of changes in suppliers and are essentially uncontrolled because of the flexibility and discretion allowed bidders by procurement specifications.

In recent years, it has been an objective of the DoD to increase the incidence of competitive procurements and, at the same time, reduce the frequency of sole-source procurements. In 1963, Secretary Morris said, "Secretary McNamara has strongly reaffirmed our goal of converting a much larger percentage of Defense procurement to price competition . . . . His statement has described our progress during fiscal year 1962 when $760 million was shifted from non-competitive to price-competitive

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[1]Task 2B-1, "Change Management," July 8, 1964.

procurement, bringing an average price reduction of 25% for each dollar shifted. . ."[1]

One of the more obvious and yet significant consequences of competitive procurement is the possibility that suppliers may change each time an item is competitively procured. Experience has demonstrated time and time again that when suppliers change, the equipment is also likely to change. It is not unusual for the Government to find that it has acquired a new version of an equipment upon reprocurement, even in those instances when detailed production data are specified in the contract.[2] When the production data allow the bidder any discretion regarding the physical or functional characteristics, as in the case of so-called performance specifications, it is virtually certain that the equipment will not be duplicated by a new supplier. We do not attempt to pass judgment on the

[1] Statement by Honorable Thomas D. Morris, former Assistant Secretary of Defense (Installations and Logistics), before the Sub-committee on Defense Procurement of the Joint Economic Committee, 28 March 1963.

[2] Major General W. T. Thurman, Hearings before Sub-committee on Appropriations, House of Representatives, 88th Congress, ". . .detailed drawings do not always assure us of obtaining identical parts." Additionally, House Reports, Volume I, 80th Congress, First Session, Report 109, page 10: "The need for standardization is also found in the fact that the parts of certain highly complicated equipment are fully interchangeable only if manufactured by the same supplier. This situation exists in the case of certain equipment even though the same specifications, drawings, and manufacturing techniques are employed. A notable example of this occurred in the case of an airplane engine manufactured for the Navy Department during the war. Two companies produced the same engine from identical blueprints; both engines performed properly; but the parts were not fully interchangeable."

advisability of allowing bidders this discretion, but merely to
state a conclusion based on innumerable comments and examples
from technical people throughout the DoD.[1]

Because of these and other factors, many within the DoD
have recognized the danger that too much preoccupation with
statistical increases in competitive procurements may preclude
adequate consideration of the economic consequences of such
competition on the total cost of meeting DoD operational ob-
jectives.

In June 1964, Mr. Robert H. Charles, Assistant Secretary
of the Air Force, said:

> ". . . let me also make clear what I mean by competi-
> tion and efficiency. These are broad terms and must
> .. defined. They include the ability to produce, not
> only with the least expenditures of resources, but as
> that .~ast expenditure relates to what we really seek--
> namely, quality, reliability, maintainability, timeli-
> ness, simplicity of logistics, etc. To construe 'cost
> effectiveness' in the narrow sense of buying the least
> expensive article is a total misconception of that
> term. Getting the right equipment comes first in mat-
> ters of national defense; and we will almost surely
> err if we blind.y adhere to a policy of buying at the
> lowest price without consideration of all the factors
> involved. (Emphasis supplied.) We would be foolish,
> for example, to compete an item for which the cost of
> reprocurement data would exceed the savings from com-
> petition. We would be equally foolish to compete an
> item if the presence of the new part thus brought into
> the inventory would create logistics problems exceed-
> ing the advantages of the cost saving thus generated.
> We would be militarily foolish to use competition if

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[1] As a qualified exception to these expressions of opinion,
the U. S. Army Electronics Command states that they have been
reasonably successful in maintaining mechanical and electrical
interchangeability of parts, sub-assemblies, assemblies and
"black boxes" through successive procurements and supplier
changes.

it would create a field situation where non-interchange-
ability of parts would prevent the cannibalization of a
disabled system from restoring another disabled system
to full utility. Surely, the saving of $1,000 is wrong
if it means that a needed $100,000 system is thereby
jeopardized."[1]

It is certain that Secretary Charles did not intend by
these comments to discourage competition in Defense procurement.
It seems equally certain, however, that he did intend to empha-
size the desirability, indeed the need, to determine, insofar
as possible, that competition accomplishes its primary objec-
tive; namely to provide the Government with the lowest total
cost consistent with its operational requirements rather than
merely the lowest purchase price. This project addresses it-
self to developing the means for effectively considering "all
the factors involved."

Major Areas of Study and Definition of Terms

The method of study adopted for this project was dictated
largely by the scope of the task order. The study effort was
divided into three major areas corresponding with the first
three objectives of the task noted on Page 1 of this report.

For purposes of this report, the term "logistics costs"
has been adopted as a generic term. It is intended to include
costs associated with or generated by the acquisition of an
equipment. It thus includes buying, training, maintenance,
documentation, special support equipment, repair parts and all
similar costs. In addition, for purposes of this project, it
includes certain limited operating costs. The word "equipment"

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[1] Honorable Robert H. Charles, Assistant Secretary of the
Air Force (Installations and Logistics), before AFLC/Industry
Management Conference, Dayton, Ohio, 25 June 1964.

is used in a generic sense to describe the primary item being procured. The terms "item" and "end item" are synonymous with "equipment."

The words "bids" and "bidders" have been used for editorial convenience to mean proposals and those who submit proposals, although generally they are used only in the context of formal advertising procedures. For reasons discussed in Part F of Section III, this study is confined to negotiated procurements thus excluding procurements by formal advertising.[1]

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[1] Page 60, infra.

II.   SUMMARY OF CONCLUSIONS AND RECOMMENDATIONS

After almost one year of study involving a large number of
field investigations and reviews of numerous other studies, we
have concluded that techniques are either available or capable
of development for predicting and measuring logistics costs
within tolerances which should permit their use in bid evalua-
tion. We have further concluded that their utility and economic
feasibility should be tested in actual competitive procurements.

In arriving at these conclusions, it has been recognized
that there are several problems yet to be overcome before the
techniques can be applied as readily and completely as desired.
The absence within DoD of adequate cost accounting systems for
collecting costs useful in logistics cost analyses has been
identified as an impediment. The need to obtain detailed de-
sign information from bidders and the difficulties of getting
this information have been recognized. Compartmentalization of
functional responsibilities within the military agencies, which
tends to isolate technical and procurement personnel from one
another, has been noted as another impediment. It has also been
observed that, in some instances, the cost of making a logistics
cost analysis may make the analysis uneconomical.

While the existence of such problems is recognized, none
appear to be insurmountable. As solutions or partial solutions
become available, logistics cost analysis in bid evaluation
should be implemented on a piecemeal basis. Delay, pending
capability to make complete analyses, is neither necessary nor
in the best interest of the Government. Any assessment of logis-
tics costs, no matter how limited, seems to us to be preferred

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to the alternative; viz., a complete disregard for the impact
of procurement decisions on such costs.

This report has pointed out that traditionally the competi-
tive decision involves a choice between two alternatives: sole
source and price competition. A third alternative has now been
introduced; namely, competition with logistics cost analysis.
Consequently, guidelines for measuring the economic feasibility
of making a logistics cost analysis have been developed for use
when competition is contemplated. In addition, ways of perform-
ing the analysis in the process of bid evaluation have been sug-
gested and illustrated.

It has been noted that logistics cost categories separate
into two functional groups; source selection and support. Source
selection costs associated with competition have been identified.
They are:

- Qualification of suppliers
- Qualification of equipment
- Patent and data rights acquisition
- Bidding

The importance of considering these costs in measuring the eco-
nomic feasibility of competition and logistics cost analysis
has been shown.

Support cost categories susceptible to influence by changes
in suppliers have also been identified. They are:

- Corrective and Preventive Maintenance
- Inventory Management
- Training
- Inspection, Installation and Check-out
- Transportation
- Documentation
- Operation

Methods for quantifying the costs associated with these categories have been suggested for use in bid evaluation. For instance, it has been shown that reliability prediction and measurement techniques exist which, together with improved maintainability prediction techniques, provide the means for forecasting maintenance costs.

This study has been concerned primarily with logistics costs which are almost exclusively associated with reparable equipments. It has been observed, however, that service life can be important in the procurement of non-reparable items. Aside from price, it is usually the only significant variable. Therefore, the Government can largely achieve the lowest total cost of non-reparables (over a period of time), consistent with operational requirements, by making service life a factor in evaluating bids for such procurements.

Numerous other studies relating to life cycle costs, many of which are referenced in this report, have been made. It has been concluded that the time has come to test the theoretical conclusions of such studies, including this study, in actual procurements. The objectives of these tests are to determine whether adequate information can be secured or developed to make reasonably satisfactory logistics cost analyses during bid evaluation, and whether such analyses are economically feasible. Expressed another way, we need to know whether or not the problems heretofore discussed can be resolved. It is believed that this question can be answered only by testing in actual procurements.

Pursuant to these conclusions, two recommendations have been made:

1. The practicability of evaluating logistics costs in procurement should be tested in actual procurements

of non-commercial reparable equipments and the guide-
lines outlined in this report should be used in con-
ducting such tests.

2. Award of contracts for non-reparable equipments on
    the basis of lowest price per unit of service life
    (e.g., mile, operating hour, calendar month) should be
    tested in actual procurements in which service life in
    excess of the minimum required is useful.

III. FINDINGS AND ANALYSIS

Part A: Scope of the Logistics Cost Problem

Research was undertaken in the early phases of the study
to establish as realistically as possible the character of the
equipment and the magnitude of procurements, in terms of dol-
lars, which might advantageously be subjected to logistics
cost analyses.

Regarding equipment character, since we are concerned with
the effect on logistics costs of changes in equipment suppliers,
our research efforts have been confined to a study of those
equipments which are either usually procured competitively or
are logical candidates for competition. Procurements of research
and development and major systems have been excluded from con-
sideration primarily because they are not usually price competed
and because of their complexity.[1] Our area of interest corre-
sponds roughly with the two categories of materiel identified
to Congress by former Secretary Morris as "military end items
and parts for such items."[2]

Military end items and parts can be separated into two
groups: reparable and non-reparable. This study has taken

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[1]Although ships, which can be classified as major systems,
are procured competitively, the life cycle cost implications of
such competition are being studied under another LMI Project
(Task 65-13).

[2]Op. cit., Footnote 1, page 6. Mr. Norris also stated
then that, "In research and development and in procurement of
aircraft and missile systems, we have very limited opportunities
to make awards on the basis of price competition."

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cognizance of both groups although many of the logistics cost categories to be discussed in Part B are seldom involved in procurement of non-reparables. Differences in <u>service life</u>[1] of a non-reparable among bidders may, however, be significant. For this reason, a recommendation relating to the treatment of service life in procurements of non-reparables is included in Section IV. The process of using measures of service life in a procurement decision is discussed in Part F.

Although non-reparables are included, it is well to remember that the logistics costs discussed herein are those most frequently associated with reparables and it is primarily with respect to such equipments that we have conducted this study.

Regarding the magnitude of procurements in terms of dollars, a study of approximately $26.? billion of procurement funds obligated in FY 1964 revealed that approximately $6.46 billion was the value of those "military end items and parts for such end items" which are regarded by this study as candidates for logistics cost analysis.[2] Of the $6.46 billion, $6.07 billion[3] or 94.0% was subjected to price competition and $0.39 billion or 6.0% was procured on a sole-source basis. Since all these procurements were logical candidates for competition, we believe the economic feasibility[4] of logistics cost analyses should have been considered for the entire $6.46 billion.

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[1] Total useful life, consisting of all in-service time between acquisition and ultimate discard.

[2] Exhibit 1.

[3] Exhibit 2.

[4] Pages 24-25, infra.

Part B: Logistics Cost Categories

The first objective of the task order was to establish
logistics cost categories. This was accomplished by research
in each of the military services and the DSA; by studies of
charts of accounts, maintenance and supply functions, training
procedures and procurement practices; by research of pertinent
literature in the form of DoD directives, instructions and
manuals; and by review of related studies.

As the investigation progressed, it became apparent that
logistics cost categories separate into two basic functional
groups. One group of costs is of a <u>source selection</u> nature,
including buying and bidder qualification activities, and the
second is of a <u>support</u>[1] nature, relating to introducing the
equipment to the field and operat ng and supporting it. Of the
two groups, the support cost categories are the most important
and will be discussed in detail.

Source selection costs subdivide as follows:

<u>Qualification of Suppliers</u>--This subdivision includes the
costs associated with surveys and other efforts required to de-
termine bidders' capabilities to produce the specific equipment
being procured and to finance the work involved. The costs are
virtually all of a manpower nature.

<u>Qualification of Equipment</u>--Included here are costs of
test equipment, manpower, transportation and reporting incurred
by the Government to qualify a new version of the product.

<u>Patent and Data Rights</u>--In this subdivision are the royalty
payments and costs of obtaining rights in data made necessary by

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[1]Exhibit 3.

the existence of a bidder's patents or data to which the Government has either no rights or only limited rights.

Bidding--Here are to be found the costs of reproduction, assembly and distribution of bid sets, including specifications and drawings. Also included are costs of analyzing and evaluating multiple bids, including the necessary negotiation associated with each bid.

Source selection costs require consideration in evaluating the economic feasibility of securing competition. Once a decision has been made to procure competitively, costs identified as Bidding need no longer be considered since the Government will have committed itself to incur the expense. Moreover, Bidding cost will not be a variable among the bidders.

Expenses associated with qualification of a new bidder and his product can, however, become a substantial cost to the Government. It will be necessary therefore to quantify these costs and specify an amount in the RFP which will represent an assessment (in bid evaluation) against all bidders and products not previously qualified.

Finally, any costs associated with the acquisition of patents and data rights or the payment of royalties might require consideration in bid evaluation. For instance, assuming one bidder has an agreement with the Government requiring payment of royalties, the RFP should specify the amount of the royalty as an assessment against all other bidders as a part of bid evaluation.

Support cost categories of Corrective and Preventive Maintenance; Inventory Management; Training; Inspection, Installation and

Check-out; Transportation; Documentation; and Operation have been identified and are discussed below in order of their importance.[1]

- Corrective and Preventive Maintenance
  1. Repair Parts
  2. Manpower
  3. Transportation

This category represents the combination of hardware, manpower and transportation costs specifically associated with the overhaul, repair and servicing of the equipment. Hardware costs include parts and components, maintenance tools and test equipment and any special facilities required to meet the maintenance requirements. Manpower and transportation costs include those associated with testing for failure, removal and re-installation of failed parts and components, transporting failed equipments to and from repair sites as required and the accomplishment of the actual repair or overhaul operations. The manpower and material costs of regularly programmed preventive maintenance complete the costs falling under this category.

- Inventory Management
  1. FSN Identification and Assignment
  2. Continuing Management

This category consists of the costs of "introducing" and managing new or additional inventory. It includes only non-hardware costs, as the costs of related hardware are covered under "Corrective and Preventive Maintenance," discussed above.

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[1] The word "importance" as used here refers to the frequency with which such costs are affected by changes in suppliers, as well as the aggregate of the funds expended each year by the DoD in each category. As will be seen, the relative importance of the categories may vary widely on a case-by-case basis.

Included in this category are the costs of assigning Federal Stock Numbers, cataloging items and parts, and completing standardization forms and similar documentation necessary to enter an equipment, sub-assembly, part or special support item into the inventory for the first time. Costs of bin opening, receiving and issue, ordering, counting and record keeping, and physical storage operations (care, preservation and packaging costs) are also included.

- Training
  1. Maintenance
     a. Hardware
     b. Manpower
     c. Training Aids
  2. Operational
     a. Hardware
     b. Manpower
     c. Training Aids

This category includes those costs necessary to provide the training required for the establishment of an in-house military capability to maintain and operate equipment. Sub-categories associated with both maintenance and operational training cost are hardware (end items and special support equipment and their parts and sub-assemblies) needed for practical demonstration and simulated maintenance and operation; manpower required for curriculum planning and instruction, as well as that consumed in trainee observation, study, and practice; and films, recordings, charts and other non-hardware training aids. Manual or handbook costs peculiar to training are included; costs associated with manuals common to both training and actual operation or maintenance are excluded from this category and covered under Documentation. The estimated cost of any contract training of Government personnel is included here.

- **Inspection, Installation and Check-out**
  1. Hardware
  2. Manpower

Here we are concerned with Government costs generated by production and acceptance inspection. Also included are those costs generated by the manpower effort involved in installation and check-out as well as costs of any hardware required, such as connections and connectors, stands and bases, special environmental facilities, calibration and test and inspection equipment.

- **Transportation**

Costs under this category are those required for movement of an end item, its spares and support equipment rrom place of production to place(s) of use or storage. Included are any indirect routing costs through Government and associate contractor facilities for modification and assembly work.

- **Documentation**
  1. Drawings
  2. Manuals
  3. Parts Lists
  4. Specifications

The documentation category includes the cost of establishing the content, writing, reproducing and distributing all of the documentation necessary to produce, maintain and operate the equipment. Such documents include drawings, sound recordings, pictorial reproductions, manuals, specifications and parts lists. Documentation peculiar to training has been assigned to the Training category; any documentation common to training and continuing operation or maintenance is assigned to this category.

- <u>Operation</u>
    1. Manpower
    2. Operating Expenses

The costs of operating an equipment are quite extensive and difficult to isolate. Operating costs with which this study is concerned are the direct manpower costs and such other direct costs as fuel, power and lubricants required over the operational life or some other specified duration.

Part C: Relative Importance of Logistics Cost Categories

The second objective of this project calls for establishing the relative importance of cost categories by equipment type. In an effort to establish such relationships, the procurement histories of several equipments were examined. They varied in complexity, cost and type from such major items as a ship's inertial navigation system (SINS) to a relatively simple aeronautical ground power supply unit. (See Exhibit 4.)

The equipments examined do not represent a valid statistical sample from which broad conclusions can be directly drawn. Difficulties experienced in obtaining logistics cost information which could be associated with particular equipments precluded sampling to such an extent in this study. To do so, if indeed it were possible, would have required at least several additional man-years of effort.

The equipments examined fall into the following classes:

Communication

Airborne

Ground

Aircraft Instrumentation

Electronic

Electro-Mechanical and Mechanical

Aircraft Accessory

Electronic

Electro-Mechanical and Mechanical

Navigation

Airborne

Shipboard

Automotive

 Combat

 Tactical

 Special Purpose

Construction

Ship's Accessory

 Electronic

 Electro-Mechanical and Mechanical

Our studies have produced these findings:

Relation of Equipment Type to Total Logistics Cost--No
firm or consistent pattern was noted or established. It is
conceivable that if a great number of procurements were ex-
amined, some pattern might emerge. The possibility also re-
mains that a much narrower definition of types or classes
might produce discernible patterns. Such narrow definitions,
on the other hand, might prove to be useless for purposes of
creating any meaningful stratification.

Relation of Equipment Type to Changes in Logistics Costs
as a Result of Introducing a New Supplier--Because of the lack
of cost information, it has been virtually impossible to make
a determination of this relationship. Under present accounting
systems, logistics costs are not collected either by equipment
type or by name of supplier. Some management systems such as
TAERS,[1] Navy Maintenance and Material Management System[2] and

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[1] The Army Equipment Record System.

[2] Tentatively approved.

the Air Force 66-1 System[1] have provisions for accumulating maintenance data by equipment type, FSN and manufacturer's name. Eventually, it may be possible to convert these data to costs. Such information, however, is not now available.

Within our ability to investigate, no patterns of relationship were indicated, although again the possibility remains that a narrower definition of classes might reveal such patterns.

Relation of Equipment Type to Relative Importance of Logistics Cost Categories--In attempting to establish this relationship, we found that, with the possible exception of Training, all logistics cost categories can apply to any equipment type except for the very simple inexpensive items. Again, no pattern of relationship was discernible.

Relation of Equipment Price to Total Logistics Cost--Some studies have indicated that the higher the aggregate prices of a group of items, the higher the aggregate of associated logistics costs. However, this relationship does not hold with any consistency on an item-by-item basis. In fact, it is not difficult to find high-priced equipments whose logistics costs are relatively low as contrasted with low-priced equipments, the logistics costs of which are quite high.

Many studies of military logistics have concluded that relatively few programs, or very few commodity categories, or a small number of major systems account for the preponderance of procurement dollars obligated during any given period. This

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[1] Air Force Maintenance Management System (AFM 66-1).

is sometimes referred to as high-dollar or high-value stratification. It is often employed as a means of emphasizing the areas in which an analysis of a problem or the application of a solution is most likely to yield the greatest return for the cost incurred.

For purposes of life cycle costing, any stratification employed should emphasize those equipments which yield the highest savings for the money expended. It must be remembered that our concern is with those logistics costs which are sensitive to changes in suppliers. Attention should be directed first to those areas which can generate the highest return, in terms of logistics cost savings, for the expense incurred in making the analyses.

In summary, the decision, whether a logistics cost analysis should be made, must depend not on equipment price or type or complexity, but directly on the economic feasibility of the analysis; and this feasibility must be evaluated on a case-by-case basis.

Part D: Quantification of Logistics Costs

The third objective of Task Order 4C-5 is the development of methods for measuring and forecasting logistics costs. An essential requirement of such methods is the ability to quantify the costs. Not only must the support costs of the existing version of the equipment be known or be capable of reasonable estimation, but also the costs which will be incurred by awarding to other than the current supplier.

If it were necessary to develop actual costs for every logistics operation of each functional category identified in Part B, the cost and time required to make an analysis would probably be prohibitive. In our opinion, however, such precision is not required. We believe the liberal use of standard costs is entirely justified as a reasonable and acceptable alternative.

For our purposes, standard costs are pre-determined costs of specific operations, established by such means as time studies, MTM or analysis of cost accounting records.

Many costs should be capable of pre-determination and application to procurements on a standard cost basis. Standard costs have been found to be in use in each of the military services, although the Air Force has developed the only group of standard costs designed exclusively for use in life cycle costing.

From the standpoint of future logistics cost analyses, this study suggests that costs of a predominantly manpower nature can best be considered if they are reduced to engineered

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[1] Air Force Real/Ultimate Cost Regulation, AFLCR 400-20, AFSCR 400-4, 14 February 1964.

standards. Standard costing procedures require identification
of manpower operations of a logistics nature. Engineered work
standards must be developed for each individual work element
comprising the operation in question. Each standard work ele-
ment is then costed on the basis of average hourly costs of the
manpower involved. The total cost of all such work elements
becomes the hourly standard cost of the operation.

Standard costs of operations can, and frequently do, vary
according to the magnitudes of such operations. For example,
the Air Force has determined that the standard cost of intro-
ducing a new FSN differs in its work content and scope depending
upon whether the new FSN is a part, sub-assembly or assembly.
Consequently, cost standards have been developed for each.[1]

In the following discussions relating to quantification of
logistics costs, those costs which might be considered on a
standard cost basis will be identified. Cost categories will
be discussed in the same order in which they were identified in
Part B.

CORRECTIVE AND PREVENTIVE MAINTENANCE[2]--This category is,
in the aggregate, the most costly of all the logistics cost
categories. The annual cost of maintenance manpower and mate-
rial for the DoD is about $13.7 billion.[3] It is important to
be able to assess maintenance cost in performing a logistics

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[1] Ibid.

[2] Because it is more complex and represents much higher
cost than the other categories, Corrective and Preventive
Maintenance is covered more extensively in the Appendix.

[3] Estimate obtained from the Directorate for Maintenance
Policy, OASD (I&L).

cost analysis, not only because the absolute cost of maintenance is high, but also because the frequency and cost of maintenance actions often vary significantly among equipments produced to the same specification by different suppliers.

There are numerous elements which must be taken into account in estimating maintenance cost of an end item over its life or for some other specified duration. These include the operating environment, equipment design, service life, parts failure rates, unit costs of parts, skills required, maintenance man-hours for the various pertinent maintenance actions, manpower cost rates, preventive maintenance plan, maintenance tools and fixtures, and transportation cost. Costs of supply and training for direct support of maintenance activities are not included because they are covered by the Inventory Management and Training categories. Administrative expenses are not included because they are not very sensitive to changes in supplier, which is our major concern.

The Government must (in order to make maintenance cost calculation possible) state in the RFP the operating environment; minimum and maximum service life which the bidder may use in the calculation; restrictions regarding available skills, tools, and fixtures; sources of failure rates and parts costs; manpower cost rates to be used; transportation cost standards; and specific procedures for the bidder to follow in supplying information relating to maintenance cost. The bidder must provide as part of his proposal the equipment design, a preventive maintenance plan, and details of his development of any maintenance information required by the RFP.

The two key questions to be answered in a calculation of maintenance cost are:

1. How frequently will the various maintenance actions be required?

2. How long will the various maintenance actions take, and how much manpower will they consume?

For meaningful consideration of logistics costs in procurement they must be capable of being answered during bid evaluation and prior to field experience with the equipment.

Reliability Evaluation - The first question is answered by a reliability evaluation. For purposes of contract award, we are concerned with the inherent reliability of the equipment, leaving such problems as manufacturing errors, operating errors, and handling damage to the control systems which are established to deal with them directly. We are concerned almost exclusively with random and wearout failures, as problems of initial failure are usually short-lived and remedied by well-established corrective procedures.

(1) Random Failures--Random failures are those whose specific times of occurrence cannot be anticipated. Estimates of their mean rates of occurrence, however, are usually obtainable. Techniques for determining how frequently the associated corrective maintenance tasks must be performed are well established. They have had extensive satisfactory application in the design and development of equipments--especially electronic equipments. They have not been used, however, in the procurement decisions in which we are interested even though these procurements are "downstream" from design and development.

One method of reliability evaluation for random failures is the Part Failure Method. It is based on the theory that the ultimate reliability of equipment depends on the reliability of the parts built into that equipment. Numerous

compilations of failure rates have been developed by both the DoD (e.g., MIL-HARK-217 and the RADC Reliability Notebook) and contractors. Procedures (e.g., MIL-STD-756A) and failure rates exist in such form that their application does not permit subjective judgment and therefore cannot bias the bid evaluation in favor of any particular bidder.

A simpler method of evaluation for random failures, commonly called the AEG Method is based on the number of active elements groups (AEG's) in the end item being considered. An AEG count is converted into a failure rate by a mathematical equation or from a graph based on the equation. Like the Part Failure Method, the AEG Method has undergone much use in design and development; results have had reasonably good correlation with actual failure rates; and the method has received DoD acceptance (e.g., in NAVWEPS 00-65-502).

(2) Wearout Failures--Wearout failures must receive different treatment from random failures in estimating maintenance cost. Wearout failures can generally be anticipated, so maintenance actions made necessary by wear phenonema (e.g., stress rupture, corrosion, fatigue) can be scheduled. Thus, such actions should be incorporated by the bidder in his preventive maintenance plan.

When wearout failure is involved, parts failure rates cannot usually be obtained from standard tables or handbooks, as they can for random failures. However, physical test for failure rate is generally feasible. Once delivered, the end item can be used for a short period of time, wear can be measured, and the measurements extrapolated to indicate when replacement or repair would be required. Thus, bidders' claims

of wearout failure rates can be used in maintenance cost calcu-
lations, for the claims of the successful bidder can be written
into his contract and demonstration tests prescribed.

There are many variations and refinements of
these approaches to reliability evaluation. Some of these are
described in detail in the references noted. This report will
not attempt to cover them completely, although they are given
more extensive treatment in the Appendix.

Maintainability Evaluation - The second question on
Page 29 is answered by a maintainability evaluation. Such an
evaluation is directed at establishing the man-hours required
for the various maintenance tasks, the frequencies of which are
provided by the reliability evaluation.

The Government may specify (in the RFP) a standard
manpower cost per maintenance action, or standard manpower costs
for various different types of maintenance action. Such costs
would only be appropriate, however, if man-hours per maintenance
action were not likely to vary significantly among the different
bidders' versions of the equipment.

In general, the bidders should be required to submit,
for each maintenance action identified in the reliability evalu-
ation, an estimate of man-hours needed to complete the action.
Any such estimate should cover as many of the following elements
as are pertinent: preparation, disassembly, and assembly; fault
diagnosis and localization; fault correction (repair or replace-
ment); cleaning and lubrication; adjustment, realignment, and
calibration; and check-out or final test. The Government should
provide standard costs for the contractor to use ir adding time
required for drawing material from stores and preparing mainten-
ance reports.

The successful bidder's figures for required mainten-ance man-hours should be incorporated in the contract and demon-stration procedures should be stipulated. An example of the requirement and associated demonstration intended is provided by MIL-M-26512C (USAF).

Another interesting technique for securing estimates of maintenance time was discovered in the course of the study. It consists of a checklist of equipment characteristics, scoring criteria for the checklist, and a regression equation for ob-taining the time estimates from scores. This technique has been used successfully, but not in enough cases as yet to merit un-qualified endorsement. For more information, the reader is referred to the Appendix.

In summary, reliability and maintainability evaluation techniques and procedures are well established and have been satisfactorily employed in design and development. In view of this capability, together with the importance of allowing for maintenance costs in making procurement decisions, a concerted effort should be made to apply them in logistics cost analyses.

If bidders can be expected to know the basic designs of their equipments, they can be expected to carry out reliability and maintainability evaluations according to well-defined pro-cedures. Such procedures can be stipulated in the RFP, and the evaluations can effectively be audited by the Government in the process of selecting the successful bidder.

Reliability evaluation identifies maintenance actions, both preventive and corrective, and the frequencies with which they must be performed. It also identifies the material (sub-assemblies and parts) required for a given period of time. Total material cost can then be computed by multiplying the number of parts required by their unit prices.

Maintainability evaluation provides the man-hours needed. Total manpower cost is obtained by multiplying the number of times the various maintenance tasks must be performed by the associated man-hours, and multiplying these products in turn by the applicable standard manpower rates.

INVENTORY MANAGEMENT--The key to computing Inventory Management costs associated with a specific equipment is the detailed design concept being proposed. In addition, the maintenance plan is needed to determine quantities, stock levels and storage points of maintenance parts; all of which directly influence inventory costs.

This is one of the more costly categories identified by this study. There are approximately 4.2 million FSN's in the DoD inventory. It has been roughly estimated that these stock-numbered items, exclusive of aircraft and missiles, are valued at $38.9 billion.[1] Estimates of the annual cost of holding an item in inventory range from 15-25% of the average inventory value.[2] Using 20%[3] and assuming that the average life span of an inventory item is ten years, the cost of holding $38.9 billion in inventory over a ten-year span is $77.8 billion.

Numerous studies and reports relating to the cost of introducing and holding repair parts in inventory have been made.

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[1] Directorate of Statistical Services, Assistant Secretary of Defense (Comptroller), advises that $38.9 billion is a reasonable estimate of value of the 4.2 million FSN's in stock.

[2] Page 36, infra.

[3] Page 37, infra.

Estimates range from $33.98 per part[1] to $3,920.46 per new repair part.[2]

In the first instance, the Air Force has included in the $33.98 only "identifiable costs associated with the specific materiel management, supply and transportation organic functions of requirements, cataloging, standardization, equipment authorization, receiving, recording, storing and freight classification."[3] "From each of these functional areas, engineered time standards were accumulated for tasks directly and wholly relating to new item input. The manpower for each of the functions was consolidated and converted to dollars."[4]

The U. S. Army Engineer Maintenance Center reports that its figure of $3,920.46 includes the costs of receipt, storage, issue, stock control, supply control, cataloging, procurement and transportation over the average life of an item in the DoD inventory.

It seems evident that the Army and the Air Force approached the problem in different ways. Yet, in essence, the cost developed by each service purports to represent the cost of adding a new part to the supply system. In fact, the Air Force, when using its Real/Ultimate Cost method of procurement assesses bidders $33.98 in the bid evaluation for each new FSN part introduced by the end item.

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[1] Op. cit., Page 26.

[2] Corps of Engineers Study, "Cost of Introducing a New Repair Part Line Item into the Engineer Repair Parts Supply System," 11 August 1958, Planning Office, U.S. Army Engineer Maintenance Center.

[3] Op. cit., Page 26.

[4] Ibid.

Other estimates of "introducing new items into the inven-
tory" and "holding in inventory" have been made. In some in-
stances, valid comparisons can be made among the various
estimates; in others, the composition differs so widely that
comparisons are difficult to achieve. Our research has included
a study of several reports from which we have developed the
following:

Cost of New PSN Introduction - Of all the costs which
can be associated with inventory management, we believe that the
cost of cataloging is the only significant one which is peculiar
to new PSN introduction.[1] Estimates of this cost vary widely.
Our research suggests that the cost of $207.00 developed by the
Army as the cost of initial cataloging and technical research
is reasonable for purposes of logistics cost analyses.[2] This
amount embraces the costs associated with item identification,
preparation of standard forms and coding of the item character-
istics, computer matching and print-out, entry into catalogs,
printing and distribution and follow-up paper work.

A prerequisite to the computation of this cost in a
logistics cost analysis is the submission of a parts list by
each bidder, identifying the parts (by PSN's when possible)
which, in his opinion, must be carried in inventory as support
or repair parts. The first and less desirable method would re-
quire a complete verification of the accuracy of each bidder's
list as to PSN identification. To accomplish this, we believe
the Government would incur approximately 90% of the cost it is

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[1] We find it more convenient and appropriate to refer to this
as PSN identification and assignment since, as will be seen, this
function does not necessarily culminate in a new PSN introduction.

[2] Op. cit., Page 34, Footnote 2.

attempting to avoid, since virtually every function, except actual catalog entry, would be performed in making the verification. Moreover, since verification would be required for every bidder, its cost would unquestionably exceed the cost of "introducing" the new item.

The second method, and the one favored by LMI, would also°require each bidder to submit a list of parts, identified insofar as possible by FSN's. The sum of the parts not so identified will be multiplied by $207.00 (or some other factor the procuring agency may select) and the product will be the cost of FSN identification and assignment. By this method, the cost will be incurred only after the successful bidder is selected and then only as to his bid, thus avoiding the cost of verifying every bid.[1]

Continuing Management - The cost of this sub-category, sometimes called the holding cost of inventory, has been the subject of many studies. Our research has included reviews of several of these studies, virtually all of which attempt to compute this cost as a percentage of the average inventory value. The percentages range from 15% to 25%. The composition of the rates generally breaks down into three groups of expenses:

- Interest on funds invested in inventory

- Warehousing activities

- Obsolescence and deterioration

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[1] Consideration of this cost in bid evaluation might possibly influence some bidders to be overly optimistic in their bids regarding the use of existing FSN's. A counter-balancing influence might appropriately be established by an RFP provision that errors discovered subsequent to award will be compensated for by contract price adjustments determined by multiplying $207.00 by the total of all such errors.

All the studies relating to Government operations have taken interest at 4% in accordance with DoD Instruction 4140.11.

The cost of warehousing activities[1] such as maintenance in storage, receiving, issue, counting, losses and handling equipment varied from 1.4% to 6%, with 5% as the mode.

The greatest variation among the studies reviewed occurred in obsolescence and deterioration. Typical of the variances are:

6.1%	-	Port Devens and Port Meade[2]
10.0%	-	Frankford Arsenal[3]
11.4%	-	Tobyhanna Signal Depot[2]
15.0%	-	Air Force Air Materiel Areas-- Ogden, San Antonio and Middletown[4]

No attempt has been made to evaluate the findings of those studies. For purposes of this project, 20% of the average

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[1] Buchan and Koenigsberg, Scientific Inventory Management. Page 288, "Holding implies two types of costs: (1) that associated with the physical presence of goods, (2) that of the capital tied up. The first of these costs includes both fixed and variable components. When goods are stored in a warehouse, the rent (or amortization cost), electricity and heat are more or less fixed; a reduction of inventory levels by, say, 20% will not reduce the cost. The labor and equipment required may, however, be a function of inventory level."

[2] Economic Inventory Policy Report #2, "The Cost of Supply Operations," prepared for Deputy Chief of Staff, Logistics, U. S. Army, by Harbridge House.

[3] M.I.T. Study, "Control Procedure for Medium and High-Dollar Value Non-Reparable Items," prepared by Frankford Arsenal for U. S. Army Supply and Maintenance Command, May 1963.

[4] Parts Support for Air Force Depot and Contractor Maintenance, Project 1D-1, Logistics Management Institute, August, 1963.

inventory value has been selected as the annual holding cost.
(However, the individual services are encouraged to develop
their own factors.) Variance about the 20% figure is not as
great as might be assumed. Obsolescence tends to be in the
upper portion of its range at depot level activities, where
warehousing cost is in the lower part of its range. At lower
level maintenance activities, the obsolescence percentage tends
to be lower and the warehousing cost percentage higher, so that
the total does not change significantly.

Numerous studies in private industry have yielded
holding costs in the range of 15% to 20% of average inventory
value, with most of the results being in the upper part of the
range. Comparing these figures with defense equipments in which
the risk of obsolescence is, in general, much higher, the 20%
figure does not appear excessive.

The cost of Inventory Management for each bidder would
thus be determined by multiplying 20% times the estimated service
life (in years) of the end item being supported, by the value (in
terms of purchase price) of the average inventory held.

Average inventory value will not usually be available
in precise terms at the time of bid evaluation, for it depends
not only upon the demand rate, but also on variability of demand,
lead time, unit cost, cost of ordering, and in fact, the holding
cost of inventory. It will generally be prohibitively expensive,
if not technically infeasible, to consider these factors directly
in computing the average inventory for each support item. A
practical method is to use actual inventory data for items of a
similar price range at similar stockage points.

Suppose the Army is buying an end item which will be
supported at the depot level by parts whose unit costs fall in

the range of $1 to $500, and that predicted consumption of these parts amounts to $1,000 per year. It would then be appropriate to secure from Army depots data regarding values of issues and inventories of parts in approximately the same unit cost range. Suppose that such data were obtained for a two-year period and averages were computed as follows:

Quarterly Issues $ 30,000

Inventory on Hand $216,000

Then annual issues would be 4 x $30,000 = $120,000, and the average inventory, expressed in years, would be $216,000/$120,000 = 1.8 years. The average inventory value would then be 1.8 x $1,000 = $1,800. If the expected service life of the end item was estimated as seven years, the inventory holding cost of the parts would be 20% x 7 x $1,800 = $2,520.

TRAINING (MAINTENANCE AND OPERATIONAL)--The estimation of training costs requires a determination of the training program in terms of numbers of training sites, numbers and types of trainees and instructors, number and duration of sessions, manuals, training aids and hardware. The program so determined provides the basis for costing the following sub-categories.

Hardware - Training hardware includes the necessary quantity of end items, special support equipment, repair parts and test equipment required specifically for training purposes. Costs of this hardware can be obtained directly from the bidders.

Manpower - Included here are the costs associated with the pay of instructors and students, their subsistence and travel and any other fringe costs associated with personnel. Engineered standards should be developed and used in costing this sub-category.

Training Aids - This sub-category includes non-hardware items such as slides, charts, mock-ups and models. Booklets, pamphlets and manuals peculiar to training are also included. Similar material used in training, but common to maintenance and operational functions, is included in the Documentation Category and is thus excluded here. Having identified the required aids, cost estimates can be made from information on file from similar situations or quotations can be secured from appropriate sources.

As in the category of Inventory Management, the key to determining the costs involved in Training is the acquisition with each bid of the detailed design concept being proposed. Since the RFP must be specific as to bid evaluation criteria and their measurement, and will of necessity be prepared without any knowledge as to how the design will vary among the bidders, it must stipulate precisely how inferences about training requirements will be drawn from design information supplied with the bids. Rules to serve this purpose will have to be established through sound engineering judgment and review of any available historical data regarding training requirements generated by supplier changes for the same or closely related equipments.

It might be concluded, for instance, that a 15% parts change would induce need for a new training program. In such event, the RFP would provide that if any proposed design were to deviate from the existing design to the extent that 15% of the parts in the current design were replaced, such bidder would be assessed an amount for additional training. The amount should include a figure computed by adding the manpower and training aid costs which would ensue. In addition, the RFP

should specify a hardware assessment, which would be made by multiplying the number of additional hardware required for training by the appropriate bidder's unit hardware price.

As noted earlier, lack of an effective cost accounting system for logistics purposes makes it difficult to determine the historical costs associated with existing equipment. In establishing cost factors to be employed in evaluating training costs associated with bidders' equipments, therefore, reliance must continue to be placed on the judgment of knowledgeable technical personnel responsible for training functions within the military agencies.

Before leaving this category, it should be noted that training, in the aggregate, is not an insignificant cost to the DoD. It has been estimated that the total cost of those subcategories listed herein approximates $1.0 billion annually.[1] While all such training is not associated exclusively with the equipments under study, nevertheless we believe it is of sufficient magnitude to be worthy of evaluation as a logistics cost.

INSPECTION, INSTALLATION AND CHECK-OUT--Like the category of Training, this category subdivides readily into labor and material costs. As in other categories, a prerequisite to cost quantification is information regarding design concepts.

Hardware - Changes in equipment configuration frequently affect the cost of inspection, installation and check-out. New bidders may require relocation or new procurement of inspection tools and gauges and other test equipment. Installation and check-out hardware requirements will be determined

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[1] Directorate for Maintenance Policy, Office of the Secretary of Defense (Installations and Logistics).

largely by the design concept. Such hardware includes, for example, connectors, bases, stands and calibration equipment.

This sub-category needs evaluation to determine what hardware will be required by virtue of changing suppliers. Its cost may be determined from information on file in the procuring agency or, when time permits, by quotations from appropriate sources.

Manpower - Labor, in terms of the technical skills required to perform operations of this functional category, is susceptible to determination. Engineered work standards and the average hourly or daily costs for each work standard can be developed. The variable in this computation is the number and extent of operations required by the design concept of each bidder. This variable must be estimated on a case-by-case basis.

The cost of this category for each bidder will be the total of labor and materiel costs, plus any transportation required to relocate or procure inspection equipment.

TRANSPORTATION--Techniques for determining transportation costs are so well established that a discussion here would contribute nothing of substance.[1] The important thing to remember is that the cost of initial transportation of the end item is only a part of the consideration. The transportation costs of maintenance parts, for example, for movement from place of production to place of storage or use, computed over the service life of the equipment, should also be considered. This cost may also vary among the bidders. Transportation for maintenance activities is covered under "Corrective and Preventive Maintenance."

[1] ASPR Section I, Part 13.

DOCUMENTATION--This category of cost, while not usually substantial in relation to Maintenance and Training, nevertheless can be significant in specific cases. Once again, details regarding the extent of design changes being proposed are required in order to quantify this category.

Given the design concept, three types of cost must be determined. First, the cost of producing the new documentation; second, the cost of conforming existing documents to the changes; and third, the cost of distributing the changed documentation. In order to develop those costs, it is necessary to know the extent of documentation changes.

The logical sources of this information are the bidders. However, the Government must make the existing documentation available to bidders if they are to be held responsible for identification of changes. This can be done by incorporating by reference the existing documentation in the RFP.

The cost of any changes required can be secured either as a line item in the hardware bid; from pre-determined cost standards; or, if time permits, by quotation from appropriate sources. In any event, the successful bidder should be required, as a contract line item, to furnish at least all original material (text and art work) involved in the document changes.

OPERATION--In the procurement of relatively complex equipments, changes in design by new bidders sometimes involve changes in costs of operating the equipment. These costs are usually reflected in additional or different types of manpower and power or fuel consumption. Manpower costs of this nature are susceptible to application of standard labor costs which can be computed for the operational life of the equipment or

some other specified time interval. The incremental manpower requirements, if any, can be determined, however, only from knowledge of the differences in designs being offered.

Fuel or power requirements can best be determined when equipment is available for pre-award testing. Since this is usually not practical, bidders should be required to provide such information. The computation of the cost can be accomplished by applying appropriate fuel rates to quantities required over the expected life span of the equipment.

Part E: Application of Logistics Cost Analyses in the Procurement Decision

Several practical problems encountered in this study have been those of determining how best to apply a logistics cost analysis; by whom it should be made; in what procurement circumstances; in what types of procurements; and at what point or points in the procurement cycle.

There are two identifiable intervals in the procurement cycle of an equipment in which logistics cost analysis plays a role. The first is when competition is contemplated. This involves consideration of the economic feasibility of competition and such analysis, which we call Mode 1. The second is when bids are evaluated. This involves actual application of the analysis, called Mode 2. Occurrence of Mode 2 depends upon the decision in Mode 1.

Traditionally, the competitive decision involves a choice between two alternatives: sole-source and price competition.[1] We are now introducing a third alternative; namely, competition with logistics cost analysis. Since there are costs associated with making an analysis, it is important to weigh such costs before deciding in favor of analysis.

It is evident that Mode 2 will not occur unless there has been an affirmative decision in Mode 1 to make a competitive procurement accompanied by a logistics cost analysis. Having made this decision, the RFP must be prepared with the analysis in mind, and the successful bidder must be selected through the analytic process described in the RFP.

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[1] Design competition, in the classic sense, is not involved in our Mode 1 since we are dealing with equipment buys beyond the R&D stage.

Mode 1 - Feasibility of Competition and Logistics Cost

Analysis---The purpose of Mode 1 is to avoid uneconomical expense
of logistics cost analysis or even competition when there is no
expected resultant benefit to the Government in terms of total
cost. An elaborate, detailed, and thus expensive Mode 1 pro-
cedure would be inconsistent with this purpose. Methods appro-
priate for Mode 1 must be restricted to utilizing pertinent data
and expert opinion which can be readily and inexpensively obtained
and reviewed. Judgment will necessarily play a vital role.

It is important to study the Mode 1 decision, including
all the questions implicit in it. These questions will be pre-
sented in this report in a sequence which portrays the logic
inherent in the decision. Few of the questions are capable of
explicit treatment within the Mode 1 limitations noted above.
Nevertheless, application of the best available judgment to the
various parts of the logical framework provided will yield
better results than over-all judgment applied to the decision
as a whole. Only by recognizing all the logic steps which would
be followed in an ideal approach (i.e., with complete informa-
tion and resources as great as desired) can it be assumed that
the judgment required is applied as effectively as possible.
Systematic application of judgment, based on less than complete
information, is not equivalent to abandonment of the decision
to intuition.

There are four different subjects of investigation in Mode 1.
One is the dollar magnitude of the logistics cost categories and
the variability of their costs among different bidders. Second,
there is the expense involved in analyzing the categories. Third,
any logistics cost advantage associated with awarding the contract
to a former or current supplier must be considered. And fourth,

MODE 1 QUESTIONNAIRE

1. What logistics cost categories are pertinent to the equipment? If none, select the Price Competition alternative, and skip to Question 16.

2. What physical or functional characteristics of the equipment influence the costs of these categories? Ⓐ

3. Which of these characteristics are likely to vary among different bidders' versions of the equipment? If none, select the Price Competition alternative, and skip to Question 16.

4. For each such characteristic, how much variation can reasonably be expected? Ⓑ

5. What is the expected cost impact of each such variation on the pertinent logistics cost categories?

6. For each logistics cost category so affected, does the equipment of any former or current supplier represent a logistics cost advantage to the Government? Ⓒ If "No" for every such category, eliminate the Sole Source alternative, and skip to Question 11.

7. What is the amount of each such advantage?

8. Does the equipment of any former or current supplier represent an advantage in more than one logistics cost category? If "Yes," what is the total advantage it represents?

9. Do the equipments of two or more suppliers represent advantages? If "Yes," which one represents the largest total advantage? If two or more represent the (same) largest advantage, eliminate the Sole Source alternative, and skip to Question 11.

10. Considering purchase price and all pertinent logistics costs, is it reasonable to assume that a bidder, other than the one whose equipment represents the largest total logistics cost advantage to the Government, can overcome that advantage as well as the additional source selection costs[1] that competition would generate? Ⓓ If "No," accept the Sole Source alternative.

11. For each logistics cost category affected by the variable characteristics of Question 3 (i.e., for each category identified in answering Question 5), what would be the cost of making an analysis in the process of evaluating bids?

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[1] Excluding possible expense of logistics cost analysis.

12. Are there combinations of logistics cost categories whose joint analysis would cost less than the sum of the costs of analyzing them independently? If "Yes," what are the combinations and what would be the cost of each joint analysis so indicated?

13. Considering the susceptibility of the logistics cost categories to cost variation (from Question 5) and the costs of analysis (from Questions 11 and 12), for which categories can logistics cost analysis be economically justified? Ⓔ If "None," and the Sole Source alternative has been eliminated,[2] select the Price Competition alternative, and skip to Question 16. If some analysis is justified and the Sole Source alternative has been eliminated,[3] select the Competition with Logistics Cost Analysis alternative. If some analysis is justified and the Sole Source alternative has not been eliminated, skip to Question 15.

14. Considering purchase price only, is it reasonable to assume that a bidder other than the one whose equipment represents the largest total advantage to the Government can overcome that advantage as well as the additional source selection costs that Price Competition would generate? Ⓕ If "Yes," select the Price Competition alternative, and skip to Question 16. If "No," accept the Sole Source alternative.

15. Considering purchase price and the logistics costs whose analysis has been economically justified,[4] is it reasonable to assume that a bidder other than the one whose equipment represents the largest total advantage to the Government can overcome that advantage as well as the additional source selection costs that Price Competition with Logistics Cost Analysis would generate? Ⓕ If "Yes," select the Price Competition with Logistics Cost Analysis alternative. If "No," accept the Sole Source alternative.

16. (Answer only if Price Competition alternative has been accepted.) Is variation in service life expected, within the span defined by the minimum the Government will accept and the maximum it is interested in, among different bidders' versions of the equipment? Ⓖ If "Yes," the contract award should be made on the basis of the lowest quotient obtained by dividing purchase price by service life. If "No," the contract award should be made on the basis of lowest purchase price.

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[2] By Question 6 or Question 9.

[3] Ibid.

[4] In answering Question 13.

FLOW CHART OF THE MODE 1 DECISION

(Referenced to the Mode 1 Questionnaire)

Competition With
Logistics Cost
Analysis

Mode 2

Sole
Source

Price
Competition
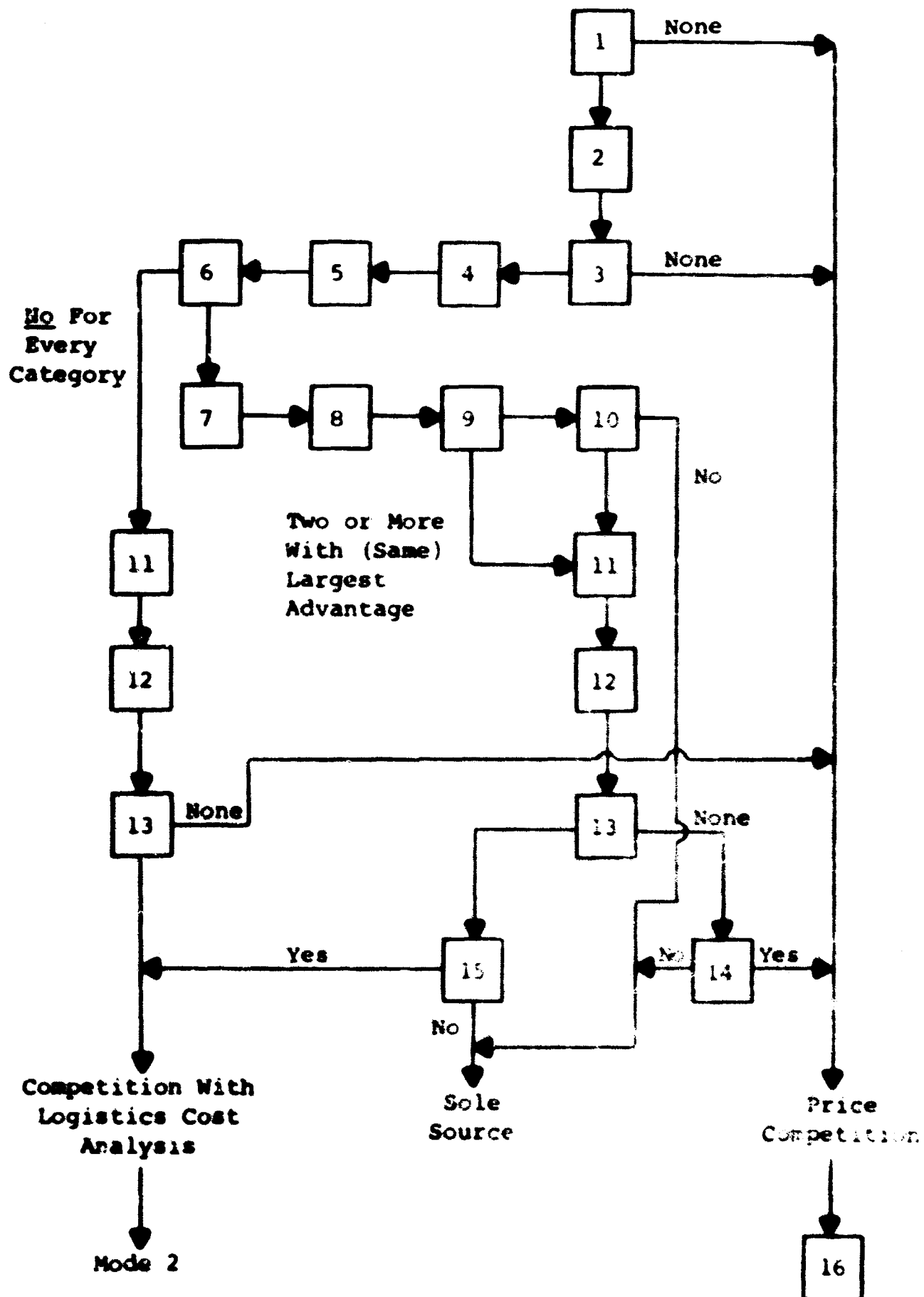
NOTES ON THE QUESTIONNAIRE

(A) The discussions of Part D cover the characteristics most likely to be identified in answering this question.

(B) "Variation" is defined to mean the difference in the characteristic between two bids representing the extreme positions for the characteristic among the bidders.

(C) The word "advantage," for purposes of the questionnaire, is narrowly defined. The equipment of a former or current supplier is said to represent an advantage to the Government, with respect to a specific logistics cost category, if the cost associated with that category would necessarily be greater as a result of contract award to any other bidder.

(D) In determining whether it is "reasonable to assume" that a potential new supplier can overcome an advantage which has accrued to a former or current supplier, it is important to consider both the probability that he can overcome it and the expected cost benefit to the Government if he does. The product of these figures should be compared with the product of the probability that a potential new supplier cannot overcome the advantage and the expected loss to the Government if competition is secured and the advantage is not overcome. If the first product is larger, the answer to the question is "Yes." If the second product is larger, the answer is "No."

(E) For analysis of a category to be economically justified, the expected cost of analysis must naturally be much smaller than the expected cost variation. The expected number of bidders and the expected distribution of analysis results for the category are factors in answering the question.

(F) The phrase "reasonable to assume" is used in the same sense as in Question 10 and Note (D).

(G) The answer to this question may have been provided in answering Question 3.

Mode 2 - Utilization of Logistics Cost Analysis--Having
determined in Mode 1 that competition with logistics cost analy-
sis will be obtained, it then becomes necessary to structure the
RFP with the analysis in mind. Specifically, those categories
which are to be analyzed (determined in Mode 1) must be covered
in the RFP with "sufficient clarity and definiteness to enable
each bidder to know precisely how the bids will be evaluated."[1]

For purposes of illustration, let us assume it has been
decided in Mode 1 that Inventory Management costs are susceptible
to significant variation among the bidders and that their rela-
tionship to the cost of analyzing the category justified the
analysis. It will then be necessary to detail in the RFP the
method to be employed in evaluating this category.

As has been noted several times in this report, a prime
requisite of the analysis is information regarding the details
of design and support (maintenance) parts. Thus, the RFP must
stipulate these as requirements. By referring to Inventory
Management in Part D, suggested methods for evaluating this
category will be found.[2] Regarding the suggested methods, it
is impo·· ·nt to note t·. whether they or some other methods
are adopted, those selected must be included in the RFP with
sufficient clarity that bic·ers can reasonably be expected to
understand how Inventory Ma agement costs are to be treated in
choosing the contractor.

Methods of quantifying costs for each of the logistics cost
categories have been discussed in this report. These methods

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[1] Page 63, infra.

[2] Page 33, supra.

should not, in any sense, be construed as being all-inclusive.
They represent suggestions only and the military agencies are
encouraged to use any other methods which are more suitable.
Nevertheless, for each category to be analyzed, a suggested
method of quantification is available and the procedure illus-
trated above may be followed in structuring the RFP.

The relative difficulty of quantifying logistics costs will
vary from item to item and from procurement to procurement.
There may be occasions when it will not be possible to devise,
in advance, a method of quantifying costs for some particular
category (e.g., Training) because the effect of predicted changes
in equipment on the costs cannot be stated equitably. In such
cases, if it is important to analyze the category and the addi-
tional expense and time has been determined in Mode 1 to be
economically justified, it is suggested that a technique similar
to two-step formal advertising be employed.[1] This will provide
a means of examining the proposed designs and determining their
effect on the logistics cost category in question prior to com-
mitting the bidder to price proposals. The request for design
proposals, in such instances, however, must alert the bidders
to the fact that the proposed designs will be studied in light
of this objective and that each subsequent request for a price
proposal (if any) will specify, in terms of dollars, the added
costs of the category to be assessed that bidder.

The next step in the procedure is the evaluation of bids,
which must be done in strict compliance with the Request for
Proposals. The sole purpose of competition with logistics cost
analysis is the selection of a contractor whose proposal repre-
sents the lowest cost to the Government, price and other factors

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[1]ASPR, Section II, Part 5.

considered. This being so, the purpose of the bid evaluation is to determine the absolute costs of each bidder, including quoted price and, as indicated by Mode 1, logistics costs and service life. There are, of course, many ways of evaluating bids, but as has been stated, the method to be employed will have been specified in the RFP. The following illustrates a bid evaluation.

Two logistics cost categories have been determined to be significant. In addition, service life has been stated in the RFP to be a variable; the minimum acceptable service life being five years and the maximum life to be considered being ten years. It is further stated that award will be made to the bidder whose bid represents the lowest cost per year. The bids are:

Bidder	Purchase Price	Preventive & Corrective Maintenance	Inventory Management	Service Life (in years)
A	$1,000	$1,000	$500	10
B	900	800	100	6
C	800	1,200	400	8

For each bid, the quoted price, Maintenance cost and Inventory Management cost are added and the sum is divided by the proposed service life. The results are:

Bidder A -- $250

Bidder B -- 300

Bidder C -- 300

Bidder A receives the award.

Part F: Problems of Application of Logistics Cost Analysis

Impediments to Logistics Cost Analysis--It was noted in Part D that an essential requirement of any method for forecasting and measuring the occurrence of life cycle costing is an ability to quantify the cost. It became evident early in the project that there are two major impediments to this requirement. One of these impediments is the absence of pertinent cost information within the DoD. The other is the lack of specifics regarding the equipment design proposed by bidders.

Cost Information Impediment - Regarding the absence of cost information, a study report dated 25 June 1962 had this to say:

> "The accounting systems of the Departments and Agencies constitute the principal means of collecting cost data for use in the Programming System. They furnish raw data inputs for the requirements models and special cost studies, and they provide feedback data for measuring performance against plans.

> "The importance of these data makes improvements in the accounting system of vital concern to Programming. On the whole, the present system is seriously inadequate for programming needs. Perhaps the most serious problem is the diversity of accounting systems presently used by the Departments and Agencies--each covering a portion of their activity, but none covering the whole. Another serious deficiency, from the programming standpoint, is the strong emphasis which DoD accounting systems place on the discharge of accountability for appropriations, funds, and cash as required by laws and regulations, rather than on cost information for management purposes.

> "Accounting data are more likely to be classified along appropriation lines than in the way programs are actually managed. Because accounting practices vary so widely among the Services--and indeed within any single Service--cost comparisons are hard to make and

uniform programming procedures are difficult to install.
Accounting reports are often ponderous things--untimely
masses of data lacking much real meaning and with no
acceptable standard by which actual performance can be
judged."[1]

The report optimistically noted, however, that costing
deficiencies had been recognized by OASD(Accounting) who had
"made a series of far-reaching recommendations which are designed
to meet the needs for better accounting data for both management
and programming."

One significant step designed to rectify accounting
deficiencies was taken in August 1963 by the issuance of a DoD
instruction.[2] Its purpose was to prescribe a uniform cost
classification structure for depot maintenance operations. Its
objective was to provide a basis for developing improved manage-
ment of depot maintenance. The Instruction, issued by the As-
sistant Secretary of Defense (Comptroller), required depot
maintenance activities to employ a cost accounting system de-
signed to, among other things, "account for all elements of
cost, as described in Section V herein, incurred in the perform-
ance of depot maintenance, including the cost of indirect support
functions and the related general and administrative support
functions, regardless of how such costs are financed."

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[1]Study Report on the Programming System for the Office of
the Secretary of Defense, prepared by Office of the Assistant
Secretary of Defense (Comptroller), Programming Directorate for
Systems Planning.

[2]Department of Defense Instruction 7220.14, August 14,
1963, "Uniform Cost Accounting for Depot Maintenance."

Section V of the Instruction specified that the following cost elements should be included:

- civilian personnel
- military personnel
- materials and supplies
- contractual services
- installation--indirect or overhead
- maintenance support
- contractual maintenance

This action is the first major effort of the DoD, noted during our research, to establish an accounting system designed primarily as a logistics management tool as contrasted with systems designed primarily to account for expenditures by appropriations and for budgeting purposes.

Approximately one year following the issuance of DoD Instruction 7220.14, DoD Instruction 7220.17,[1] designed to provide uniform cost accounting for supply activities, was issued. While the results have not yet been evaluated, it is believed that these Instructions, if vigorously implemented, will produce valuable information for logistics cost analysis.

Design Information Impediment - This report has pointed out that attempts to quantify logistics cost are dependent, in virtually every cost category, upon specifics regarding equipment design. Unless the Government is in a position to compare details of design, including such things as reliability, maintainability, repair parts and special support equipment, it will be impossible to make any meaningful analysis of the differences in cost among bidders. Information relative to each particular

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[1] DoD Instruction 7220.17, "Uniform Cost Accounting for Major Supply Activities," 21 August 1964.

design concept therefore, must be supplied by each bidder.[1]
Detailed definition of design traditionally has not been sup-
plied by or required of bidders; nor has it been traditional to
require lists of spares with bids. To the contrary, spares are
usually provisioned from 3 to 18 months after contract award.

A major question confronting us therefore has been: Can
the Government secure the needed design information without incur-
ring unreasonable cost and within acceptable periods of time?[2]

As to the question of cost, we believe that in the
vast majority of cases the Government will incur little or no
additional direct cost.[3] It is very probable that bidders will
be put to additional expense which will undoubtedly be reflected
in increased overhead. This will ultimately be reflected in
additional cost to the Government if all bidders continue to
do business with the Government.[4] This additional cost is ex-
tremely difficult to isolate and measure.

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[1] In the purchase of commercial (off-the-shelf) equipments,
a sample of the item itself may be supplied. In such a case, the
need for design information cannot be regarded as an impediment.

[2] Bidders' ability to supply details of design will depend
heavily on the Government's definition of the operational and
maintenance plans in the RFP's.

[3] There will be occasions, such as have been seen at the
Army Tank-Automotive Center, when the Government may purchase
samples of major equipments for extensive test and evaluation.

[4] In this connection, it is well to remember that the Govern-
ment historically has followed a policy of encouraging industry
to bid freely for Government business. Every evaluation of com-
petition tends to equate freedom of competition with greater
numbers of bidders. Only one bidder, in most instances, is
successful. Meanwhile, many bidders have incurred the cost of
bidding which must somehow be recovered. It is logical to as-
sume that those costs are now being passed on to the Government,
at least in part, in the form of increased overhead.

We believe that if bidders are required to submit de-
tailed and specific design information with each bid, the number
of bidders may well be reduced, primarily among those fringe
bidders who have no real qualification in the instant procure-
ment. We further believe that this reduction will have the
effect of off-setting the additional costs which will be incur-
red by fewer, but generally better qualified bidders, without
impairing the effectiveness of the competition.

We have concluded therefore that increases in cost to
the Government for the additional effort required of bidders may
be more illusory than real. Actual tests should determine whether
we have postulated correctly.

Regarding the additional time which may be required,
we are of the opinion that better advance procurement planning
should effectively overcome this obstacle. Other studies by
the military services and LMI have clearly enunciated the ad-
vantages and importance of advance planning, which should pro-
vide the additional time, particularly if the advance planning
is coupled with an expanded use of multi-year contracts.

There are at least two precedents for requiring the
kinds of information being considered here. One is the practice
of securing bid samples. Another is the use of two-step formal
advertising. Although this report is not directed-to the use of
logistics cost analysis in formal advertising,[1] its techniques
are certainly adaptable to negotiated competition whenever they
can advantageously be employed. Virtually the only difference
between two-step formal advertising and the use of a logistics
cost analysis in negotiated competition is delayed submission

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[1]Page 60, infra.

of price proposals in the first instance, and a concurrent submission of technical and price proposals in the second. The latter is actually preferable from a time standpoint.

Appropriation and Organization Impediments - In addition to cost and design information impediments, there is another obstacle which ultimately will require attention. This is the obstacle inherent in appropriation methods and separation of functional responsibilities.

Usually end items are procured against one appropriation and logistics functions are supported by others. For instance, the costs of maintenance, supply and training are rarely charged to the appropriation used for procurement of end items. By the same token, individuals responsible for establishing operational requirements for end items are distinct from those responsible for maintenance or supply or training.

This diffusion of responsibility and multiplicity of appropriations seems to have produced parochial interests in those responsible for administration of appropriations. Each is motivated to use the funds assigned him to achieve maximum results in his own specific area and is not motivated to consider the effect of his actions on costs of other functions. Thus, the importance of assessing total over-all costs is obscured.

This obstacle is illustrated by the reluctance of those responsible for operational requirements to sacrifice procurement funds in favor of beneficial reductions in logistics costs. This is not surprising since, to date, there has been no convincing way to demonstrate such reductions before the fact. Moreover, the lack of a firm policy requiring logistics

cost analyses in competitive procurements and, more importantly, supporting those at the operating level who attempt to consider logistics costs, adds to this impediment. Finally, compartmentalization of functional responsibilities, a common characteristic of the military agencies, has tended to isolate technical and purchase personnel from one another, resulting in inadequate consideration of all pertinent factors at appropriate times in the procurement process.

Hopefully, demonstration of reliable methods of making logistics cost analyses will be helpful in alleviating these obstructions. The issuance of a firm policy statement at an appropriate time (preferably after successful testing of logistics cost analyses methods) seems desirable.

Finally, a greater degree of joint and cooperative effort is required among Engineering (including Requirements). Maintenance. Supply. Training. Comptroller and Purchase functions in making competitive procurement decisions. It cannot be over-emphasized that a logistics cost analysis requires the utmost in team effort by individuals responsible for such functions.[1] The weapon system management concept represents one

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[1] Rear Admiral E. E. Fawkes, Bureau of Naval Weapons. Presentation to NSIA Maintenance Advisory Committee, Williamsburg, Virginia, 3-5 June 1962. "Coordination of decisions related to support equipment repair parts and technical manuals is very difficult, and is seldom achieved with complete success. The timeliness of these actions is also subject to question. These actions are usually taken after the weapon system technical characteristics are well established and when we are confronted with a rather inflexible demand for support resources, we are victims of the classic maintenance problem: the normal reaction is that we are too early, yet when we are permitted to participate in the weapon system development program, we find we are too late. The design is frozen and we must obtain the readiness resources which the design of the weapon system dictates. We find at this time there is no maneuvering room in the support

approach to this problem. It must be borne in mind, however, that the preponderance of equipments subject to logistics cost analysis are not candidates for systems management. It is necessary, therefore, to devise ways of creating greater team effort within the functional organizations of the military services.

While this problem has been observed during our study, no effort has been devoted to its solution. Interfaces between the technical and procurement personnel and functions are the subject of an LMI reconnaissance study.[1]

Testing of logistics cost analysis techniques will go far to either validate or vitiate these conclusions.

Application of Logistics Cost Analyses to Formal Advertising-- This report has heretofore addressed itself exclusively to negotiated procurements. Early in the project, however, study was devoted to the propriety of considering logistics costs in the evaluation of bids submitted pursuant to the formal advertising procedure. Section 2305 (c) Title 10, United States Code provides that such bids "shall be opened publicly at the time and place stated in the advertisement. Award shall be made . . . to the responsible bidder whose bid . . . will be most advantageous to the United States, price and other factors considered." (Emphasis supplied.)

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decision-making process and we have lost the lead time required for obtaining and training personnel; the development, evaluation and production of training devices and support equipment; and the timely procurement and distribution of spare parts and manuals."

[1]Organizational and Procedural Guidelines for Optimization of Technical/Procurement Interfacing.

It would seem therefore that from a legal viewpoint, the
DoD need not make awards based only on the lowest quoted price.
This has been confirmed by the Comptroller General in several
decisions. In B-151177 dated 17 June 1963 he stated:

> "It should be pointed out that, contrary to the
> implications raised in your letter, our Office has
> expressly held that the cost of maintenance and opera-
> tion of equipment is of primary importance and that no
> legal objection is seen to the issuance of a specifi-
> cation advising prospective bidders that such elements
> will be taken into consideration in addition to price
> in the acceptance or rejection of bids. 36 Comp. Gen.
> 380, 384 citing A-50925, September 21, 1933. To the
> same effect with reference to the cost of Government
> inspection see 8 Comp. Gen. 649. With respect to the
> stated factors of installation expense and need and
> cost of spare parts it is not uncommon for invitation
> for bids to provide that such factors will be taken
> into consideration in evaluating bids and we have not
> objected to the consideration of these factors. Sec.
> 36 Comp. Gen. 380 and B-126830, February 21, 1956. In
> the latter decision we stated, in pertinent part, that:

>> 'In the evaluation of competitive bids, the
>> rule has been established that only such factors
>> (other than prices bid) may be considered as
>> have been clearly indicated by the invitation
>> or may be considered to have been necessarily
>> known to all parties, such as transportation
>> costs where the articles offered are priced
>> at a point other than that at which they are
>> desired. The language of paragraph 15 of this
>> invitation . . . that any element which would
>> affect the final cost to the Government would
>> be considered, may be sufficient to justify the
>> use of installation costs of the equipment in-
>> volved--foundation, building, and cooling ap-
>> paratus--as a factor in evaluating the bids
>> received, since the necessity for such instal-
>> lation was obvious from the very nature of the
>> requirements stated . . . .'

> "The chief legal problem that arises in connection
> with the factors discussed above is not whether such

factors may properly be used in evaluating bids, but
whether these factors can be stated with sufficient
clarity and definiteness to enable bidders to know
precisely how their bids will be evaluated.   Such
knowledge is imperative if bidders are to compete
on an equal basis as required by the laws governing
formal advertising.   As stated in 36 Comp. Gen. 380:

> 'The "basis" of evaluation which must be
> made known in advance to the bidders should
> be as clear, precise and exact as possible.
> Ideally, it should be capable of being stated
> as a mathematical equation.   In many cases,
> however, that is not possible.   <u>At the minimum,
> the "basis" must be stated with sufficient
> clarity and exactness to inform each bidder
> prior to bid opening, no matter how varied the
> acceptable responses, of objectively determin-
> able factors from which the bidder may estimate
> within reasonable limits the effect of the ap-
> plication of such evaluation factor on his bid
> in relation to other possible bids</u>.   By the
> term "objectively determinable factors" we mean
> factors which are made known to or which can be
> ascertained by the bidder at the time his bid
> is being prepared. . . .' (Underscoring supplied.)

"While we recognize and agree that it would be
in the Government's best interest to make such fac-
tors as you list a part of all bid evaluation for-
mulas so as to arrive at the lowest 'total cost,'
it must be noted that the factors listed cannot in
every instance be described or evaluated with the
precision and accuracy required by the formal adver-
tising laws.   In those cases where such factors can
be so described and evaluated we have held, as noted,
that they properly may be included in the bid evalua-
tion formula and, conversely, when this cannot be done
we have held that the bid evaluation formula should
not contain such factors.   For examples, see 33 Comp.
Gen. 108 with respect to the factor of prospective
depreciation on automobiles; 35 Comp. Gen. 292 for
administrative expenses and interest incident to
progress payments; and 38 Comp. Gen. 747 for main-
tenance costs over a 30-year period."

The major conclusion to be drawn from this opinion is that no legal objection is seen to considering logistics costs, in addition to price, in accepting or rejecting bids; provided that only those factors (other than price) may be considered which have been stated in the invitation with "sufficient clarity and definiteness to enable bidders to know precisely how the bids will be evaluated."

The clarity and definiteness required by the Comptroller General may prove to be somewhat difficult to attain until experience has been gained in the use of logistics cost analyses. We believe therefore that until the required proficiency is developed, their use should be confined to negotiated procurements.[1]

In this connection, it is interesting to note that of the $4.07 billion[2] competed by formal advertising during FY 1964, $2.58 billion was for commodities which have no logistics cost implications. The balance of $1.49 billion was included in the $6.46 billion[3] of items which would have been subject to analysis. If logistics cost analysis had been confined to negotiated procurements, the $1.49 billion would naturally have been excluded since it was obligated by formal advertising. Nevertheless, over 75% of the "military end items and parts fo. such end items" would have been candidates for analysis if the technique had been available in 1964.

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[1] The one exception to this general conclusion relates to consideration of service life in negotiated and advertised procurement of non-reparables and is covered in Section IV.

[2] Exhibit 2.

[3] Exhibit 1.

<u>Application of Logistics Cost Analyses at the Subcontract
Level</u>--In consideration of the millions of dollars spent by
prime contractors for equipments similar in nature to those
bought directly by the Government and with which we are con-
cerned, attention has been given to the utility and practicability
of requiring logistics cost analyses of prime contractors in their
subcontracting decisions.

While such an idea seems appealing on the surface, particu-
larly in view of the emphasis being given to greater subcontract
competition, a closer examination of its implications reveals
its impracticability and indeed its needlessness.

First, if we are to consider subcontracts for <u>production</u>
quantities of equipment, we would perforce be imposing the re-
quirement for logistics cost analyses on <u>production</u> prime con-
tractors. That being so, the prime contracts are likely to be
firm-fixed-price, fixed-price-incentive and cost-plus-incentive-
fee types, in that order of preference.

We know of no way the Government can require a prime con-
tractor to award a subcontract, resulting from competition, on
the basis of logistics cost analysis without specifically re-
serving such right in the prime contract. The standard "changes"
clauses do not grant such right nor do clauses providing for
consent to subcontract or subcontract approvals. In the absence
of a unilateral right reserved to the Government, it is not
reasonable to expect contractors willingly to increase their
costs, thus reducing their profits, by carrying out logistics
cost analyses or by awarding subcontracts to other than the
lowest bidder in order to save the Government subsequent logis-
tics costs.

It is possible, of course, for the Government to reserve
the right, by contract, to require its contractors to make logis-
tics cost analyses. Certain disadvantages, however, become im-
mediately apparent.

First, the prime contract would be subject to an increase
in price to cover additional cost each time the analysis re-
flected an increase.

Second, the Government would be required to participate in
the analysis since much of the logistics cost information must
come from the Government.

Third, whether the analysis were economically feasible in
each subcontracting decision would necessarily be a decision of
the Government since the cost of the analysis and any subsequent
cost of awarding to other than the lowest bidder would be borne
by the Government.

In our opinion, a more practical method of dealing with
this problem is provided by the controls being imposed on prime
contractors by ANA Bulletin 445 and its proposed successor mili-
tary standard. We understand that contractors will not be allowed
to make changes in the end product, after formal configuration
controls have been imposed, if such changes, including changes
in subcontractors, adversely affect the interests of the Govern-
ment. While the interest of the Government is being broadly
interpreted, it is also being very explicitly defined. In de-
termining whether a change creates an adverse effect, the same
logistics costs considered in this study are considered in ap-
proving or disapproving the change.

A significant difference between requiring prime contractors
to make a logistics cost analyses on the one hand and relying on

ABA Bulletin 445 on the other, clearly favors the latter. From our viewpoint, the difference is requiring consideration of an analysis in every subcontracting decision in the first instance and making an analysis only when a proposed change in subcontractors will affect the Government's interest in the second. There can be a vast difference in cost between the two.

Part G: Alternatives to Logistics Cost Analysis

Efforts have been made in this study to consider suitable alternatives to logistics cost analysis which might be effective in minimizing life cycle costs. Although relatively little effort has been devoted to this aspect of the task, it is possible to report the following observations.

Detailed Specifications, Plans and Drawings--In theory, the most effective alternative method for minimizing life cycle costs is to use rigid, detailed specifications, plans, drawings and bills of materials and to refrain from all changes except those evaluated on a logistics cost basis. Although theoretically this may be effective, most DoD technical personnel questioned stated that the use of such data is neither practicable nor workable. This school of opinion holds that such rigidity would tend to discourage advancements in technology and improvements in equipment. The theory is also advanced that prospective bidders would be discouraged if they were deprived of the opportunity to make design changes in order to take maximum advantage of their own peculiar manufacturing techniques, skills, materials, vendors and facilities. Moreover, as we have seen, so-called detailed production data do not assure receipt of identical equipment nor do they preclude completely the need for logistics cost analyses.

Our research has led us to conclude that heavy reliance on performance specification stems largely from a lack of engineering manpower within the military services available to evaluate the technical production data in their possession. For this reason, there is little confidence in the integrity of the data for reprocurement purposes. As a consequence, performance specifications are made controlling even when detailed procurement data are included in the contract.

With the increasing emphasis being placed on design and
production data, project definition, rights-in-data and con-
figuration management, it is possible that a renaissance in the
use of detailed procurement data packages may be taking place.
Realistically, however, we believe that it will be quite some
time before confidence in detailed data is sufficient to serve
these needs. We have little hope for it as an early alternative.

__Failure Free Warranty__--Another alternative to logistics
cost analysis, or more properly, a partial alternative, has been
introduced to the DoD in recent months. It was conceived by the
Instrument Division of Lear Siegler, Incorporated and is called
"Failure Free Warranty."

According to Lear Siegler, Failure Free Warranty

". . . places full financial responsibility for reli-
ability performance throughout product life squarely
on the contractor. It provides the maximum incentive
for constant value engineering and reliability improve-
ment through the elimination of known and observed
failure mechanisms. Decisions with respect to trade-
offs between technical and logistics considerations
must be made and paid for by the contractor. Air
Force support logistics for the product are nominal,
or eliminated entirely.

"Failure Free Warranty represents the best possible
instrument for ensuring truly fair and equal compe-
tition. All bidders must recognize and provide for
not only the production costs, but for all costs as-
sociated with maintenance and support of the product
during its service life. Irresponsible contractors,
who lack full confidence in their own capabilities
and in the integrity of their product, will tend to
eliminate themselves prior to the competitive process.

"In conclusion, we believe that, for certain products,
Failure Free Warranty provides the best possible
guarantee of optimum reliability and operational ef-
ficiency. We can conclusively demonstrate that it
collaterally offers the Government an opportunity for
major cost savings and precise budgetary control."

The Failure Free Warranty concept envisages a guarantee by contractors that their products will be free of all defects in material and workmanship for a period of years or for a number of hours of operation when properly installed and operated. Defects or failures occurring within the warranty period will be repaired or replaced by the contractor at no additional charge to the customer upon receipt of verification. The Government resident quality control inspector is to be the final authority for repair responsibility.

The merits of this concept, as seen by Lear Siegler are:

- It provides an enforceable guarantee with minimum exceptions

- It provides for practical definitions of failure criteria

- It increases operational readiness due to contractor incentives to reduce failure rates

- It reduces cost for detection, isolation, removal, transportation

- It shortens pipelines by guaranteeing a specific repair/turnaround period

- It reduces logistics costs by

    --eliminating need for spare parts procurement or inventory

    --eliminating breakout problems

    --eliminating repair depot tooling facilities or personnel

    --reducing data acquisition

- It guarantees budget control

Lear Siegler believes that contractors will have to be relieved of configuration management and engineering change controls, except for form, fit and function if the failure free warranty concept is to work. They also suggest that, at least

initially the concept be applied only to sealed units which are not to be broken open in service and that the procurements be on a multi-year basis in order to provide sufficient quantity over which to spread the additional costs which will be incurred.

Although it now appears that Failure Free Warranty may be rather limited in its application, this limitation cannot be satisfactorily measured except by experimentation, which we encourage.

IV. CONCLUSIONS AND RECOMMENDATIONS

Conclusions

Numerous studies and reports have been reviewed and a sub-
stantial number of field investigations have been carried out in
the course of this project. It has become evident that past
studies have produced a consensus that the effect of competition
on logistics cost can be measured in varying degrees and considered
in evaluating bids. Our study has shown that reliability pre-
diction and measurement are well within the state-of-the-art.
Prediction techniques for maintainability are constantly im-
proving. Maintenance costs, being a function of the frequency
of repair and the cost per repair (i.e., of reliability and
maintainability), would thus seem to be surrendering to fore-
casting techniques. The study has likewise suggested ways of
computing other logistics costs.

That problems exist and, in some instances, information is
either deficient or totally lacking is acknowledged. Two major
impediments have been discussed in some detail. The first im-
pediment, lack of an effective cost accounting system, is at
last receiving high-level attention. The issuance in August
1963 of DoD Instruction 7220.14, the purpose of which was to
prescribe a uniform cost classification structure for depot
maintenance, is a promising step toward providing a cost system
geared to the needs of logistics managers. DoD Instruction
7220.17 of August 1964, designed to provide uniform cost account-
ing for supply activities, represents a further effort to collect
costs useful in logistics management.

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In February 1965 a planni g group was convened in the DoD
to review the entire subject of financial management. The group
was comprised of representatives of the General Accounting Office,
Bureau of the Budget, OASD (I&L), OASD (Comptroller), Army, Navy,
and Air Force. Its objective was to evaluate the desirability
and practicability of adopting an integrated, uniform accounting
system to serve all management needs of DoD as well as appropria-
tion, budget and all legal requirements. Thus this group consti-
tutes another practical demonstration of the concern over accounting
problems encountered at almost every level of DoD management.

The second major impediment to the application of logistics
cost analysis relates to the difficulty of obtaining detailed
design information, including spares identification, from bid-
ders. While the problem is recognized, our study suggests that
bidders can supply such information with bids at little or no
increase in cost to the Government. It has been pointed out that
the two-step formal advertising technique has established a pre-
cedent for obtaining specific design information prior to an
award.

In addition to the two major impediments, compartmentaliza-
tion of functional responsibilities within the military agencies,
separating those persons who must jointly carry out any logistics
cost analyses, has been noted as another obstacle.

In spite of the impediments, we believe there is a capa-
bility within the DoD to deal effectively with logistics costs
in the procurement decision process. Ways of considering and
measuring such costs have been suggested.

As a consequence, it has been concluded that the time has
come to test, in actual procurements, the practicability of

evaluating logistics costs. The guidelines outlined in this report should be made a part of such tests. In order that the tests include both examination of the cost and design information impediments and quantification of logistics costs, they should be restricted to non-commercial, reparable equipments.

For non-reparables, changes in suppliers do not usually produce consequential changes in logistics costs. Service life may vary significantly, however, among different bidders' non-reparable equipments. Thus a fixed quantity of a non-reparable purchased from one supplier may represent a different amount of utility (i.e., a different total number of units of service life) from the same quantity purchased from other suppliers. The Government's interest is not necessarily served best by selecting the lowest price per unit of equipment. To the contrary, selecting the lowest price per unit of service life is to be preferred. It appears then that, when service life in excess of the minimum required is useful, variation in service life should be a major factor, along with purchase price, in the award of contracts for non-reparables. Accordingly, it has been concluded that such service life consideration should be given prompt and comprehensive testing in actual procurements.

Recommendations

In line with the above conclusions regarding expediency of testing (1) the practicability of evaluating logistics costs in the procurement of non-commercial reparable equipments and (2) award of contracts for non-reparable equipments on the basis of lowest price per unit of service life, two recommendations are presented:

    1.   Tests, utilizing actual procurements, should be undertaken to assess the practicability of evaluating

logistics costs in the negotiated competitive procurement
decision process; i.e., to assess whether adequate infor-
mation can be secured or developed to make logistics cost
analyses which are satisfactory for use in bid evaluation
and whether such analyses are economically feasible.

In implementing this recommendation three teams of individu-
als should be formed, one in each of the military services. Each
team should be under the management of a test director and
membership should consist of representatives of Procurement,
Engineering (including Requirements), Maintenance, Supply
(Inventory Management) and Comptroller. In addition, Training
should be represented as needed. It is important that the
responsibilities assigned each team member correspond to the
organizational function which he represents.

All tests should be under the general surveillance of an
OSD Ad Hoc Committee,[1] chaired by an individual reporting di-
rectly to the Assistant Secretary of Defense (I&L). This
committee's first responsibility should be to establish ground
rules for the tests. It should then refrain from active par-
ticipation, except for providing guidance when requested by the
individual teams. Finally, it should carry out a complete,
detailed analysis of each test. (All recommendations contained
herein relating to test procedures should be subject to the
committee's acceptance.)

The test director of each team should select from his own
military service a planned reprocurement of a non-commercial,

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[1]The DoD Planning Group for Spare Parts Pricing might
serve as an appropriate prototype for this Ad Hoc Committee.
For further information, see "Guide for Testing Application of
Price Catalogs in the Procurement of Sole Source Replenishment
Spare Parts;" OASD (I&L) November, 1964.

reparable end item which, if possible, is open to competition
for the first time. After the selection has been made, each
team should apply the logic outlined for use in Mode 1.[1] Any
additional appropriate questions should be pursued. Successes,
difficulties and failures associated with each question should
be carefully recorded as should the means employed by the team
to secure information. Where vital information is lacking, it
should be so noted.

Should Mode 1 produce a decision to procure sole source or
to secure price competition (without logistics cost analysis),
a report of the decision should be prepared and forwarded to
the appropriate service representative on the OSD Ad Hoc Com-
mittee. The test director should then select another procure-
ment to be subjected to the Mode 1 procedure. This process
should be continued until the team has reached a Mode 1 verdict
to secure competition with logistics cost analysis.

The team should then proceed to the preparation of the RFP.
This report may serve as a guide in preparing the RFP. When
proposals are received, the analysis should be made as promptly
as possible.

In each instance, estimates of the cost of making the analy-
sis for each logistics cost category must be carefully recorded.
Each team should then record as accurately as possible the actual
cost of the analysis. Bidders should be requested to provide
information as to their costs of developing and supplying details
of design and spares requirements as well as all other additional
costs occasioned by the logistics cost provisions of the RFP.

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[1]Page 48, supra.

The cost of and time required for negotiating the final contract should be recorded. Bidders' reactions and general attitudes regarding any aspect of the procurement should be carefully noted.

Upon completion of each test, a complete analytical case history should be prepared for study and evaluation. Each case history should comprehensively report every facet of the test; e.g., the problems encountered and all attempts at solution, whether successful or not; recommendations for avoiding or eliminating impediments; standard costs used and how they were developed; any additional cost categories or sub-categories which should be included; and details considered pertinent to an understanding of the test results.

Case histories should be analyzed by the OSD Ad Hoc Committee after which ensuing recommendations regarding additional studies or implementation procedures should be made to the Assistant Secretary of Defense (Installations and Logistics).

2. The award of contracts for non-reparable equipments on the basis of lowest price per unit of service life should be tested in actual procurements.

Accomplishment of this recommendation should be independent of Recommendation 1. Not only does this recommendation pertain to a separate class of equipments; it permits different implementing organization and procedure, which should more readily produce conclusive results. Furthermore, since it is so limited in scope, the reasons previously given[1] for confinement of the study as a whole to negotiated procurements are not germane. Hence, this recommendation allows immediate application to formal advertised procurements.

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[1] Page 60, supra.

It is suggested that the Assistant Secretaries (Installations and Logistics) of the respective military services and the Director of the Defense Supply Agency each select a procuring activity to serve as a test activity. The Head of the Procuring Activity in each instance should take whatever action is appropriate, including appointment of a test director, to initiate testing. The test director should apply the following procedure in reprocurement of non-reparable equipments which have previously been purchased to specifications stipulating minimum or fixed service life.

Prior to release of an IFB or an RFP for a non-reparable item, appropriate personnel should establish whether service life in excess of the minimum required would be useful. If they decide in the affirmative, they should further establish a "ceiling," above which additional service life does not necessarily constitute an advantage to the Government. The contract should then be awarded on the basis of the lowest quotient obtained by dividing purchase price by service life. Any service life amount used in such a calculation would necessarily be restricted to the range defined by the minimum acceptable and the ceiling.

Based on the operational and environmental conditions and the service life definition stated by the Government, each bid (proposal) should be required to include the service life claimed for the proposed equipment. The ensuing contract should specify the service life upon which the award was predicated. Compliance with this specification presents the same problems as does compliance with a minimum or fixed service life. Thus, it is essential that demonstration procedures for service life be stated explicitly and in detail in the IFB(RFP). These procedures

should be of the same type as would be necessary to assure the effectiveness of a minimum or fixed service life.

The tests should be continued until each test activity has made twenty-five to fifty contract awards on the basis of lowest price per unit of service life. The test director should then complete his analysis of the results and prepare a test report for the Head of the Procuring Activity. This report should include, as an appendix, the service life portion of each IFB or RFP in the test, the price/service life calculation performed in evaluating each bid or proposal, and individual descriptions of all problems encountered. The report should be sufficiently comprehensive to enable the Head of the Procuring Activity, after study and evaluation, to make recommendations regarding full implementation to the appropriate Assistant Secretary (I&L) or the Director of DSA.

EXHIBIT 1

ANALYSIS OF PROCUREMENT FUNDS

OBLIGATED IN FY 1964

(in billions)

Total Procurement from all U. S. Firms		$26.221
Less Missile Systems	$5.579	
(Excluding Spare Parts & Major Components)	.211	5.368
		$20.853
Less Aircraft	6.067	
(Excluding Spare Parts & Major Components)	1.237	4.830
		$16.023
Less Ships	1.480	
(Excluding Spare Parts & Major Components)	.080	1.400
		$14.623
Less Ammunition		.660
		$13.963
Less Services		1.800
		$12.163
Less: Subsistence	.579	
Textile, Clothing and Equipage	.262	
Fuels & Lubricants	.788	
Construction	1.360	
Less than $10,000	2.710	5.699
		$ 6.464

EXHIBIT 2

ANALYSIS OF PROCUREMENTS

SUBJECTED TO PRICE COMPETITION

(in billions)

(FY 1964)

Formally Advertised		$ 4.07
Negotiated		6.96
Total Competed		$11.03
Less Ships Competed	$1.05	
(Excluding Spare Parts and Major Components	.08	.97
		$10.06
Less:		
Ammunition	.298	
Fuels and Lubricants	.720	
Textiles, Clothing and Equipage	.259	
Subsistence	.560	
Construction	1.250	
Services	.902	3.989 ~ 3.99
		$ 6.07

EXHIBIT 3

SUPPORT COST CATEGORIES

- **CORRECTIVE AND PREVENTIVE MAINTENANCE**

  --Repair Parts

  --Manpower

  --Transportation

- **INVENTORY MANAGEMENT**

  --PSN Identification and Assignment

  --Continuing Management

- **TRAINING**

  --Maintenance
  - Hardware
  - Manpower
  - Training Aids

  --Operational
  - Hardware
  - Manpower
  - Training Aids

- **INSPECTION, INSTALLATION AND CHECK-OUT**

  --Hardware

  --Manpower

- **TRANSPORTATION**

- **DOCUMENTATION**

  --Drawings

  --Manuals

  --Parts Lists

  --Specifications

- **OPERATION**

  --Manpower

  --Operating Expenses

EXHIBIT 4

EQUIPMENTS EXAMINED

Ships Inertial Navigation System

M113E1 Armored Full-Tracked Personnel Carrier

Heavy Equipment Transporter

   Truck-Tractor (25 Ton, 6x6, M523E2
        FSN 2320-226-5769)

   Semi-Trailer (55 Ton, Low Bed, M524E2
        FSN 2330-226-5770)

M48 A1 Tank

Commercial Engine (Diesel or CIE Fuel) for the
     Army's M39 Series 5-Ton Truck

          Mack Model (ENDTL)

          Cummins Model

          Continental Model

Commercial Engine for the Army 10-Ton Truck

          Mack Model (ENDT T-864)

          GM Model (8V-71)

          Cummins Model (V8-300)

Truck (cargo) 2 1/2 Ton XM-410E1

Truck (cargo) 2 1/2 Ton M-35

Truck (cargo) 5 Ton XM-656

Truck (cargo) 5 Ton M-54

Air Force TACAN Equipment (AN/ARN-21)

Surface Search Radar

Radar Nose Cone Assembly for F8U Aircraft

EXHIBIT 4
Page 2

ARC-84 VHF Transceiver

ARC-52 UHF Transceiver

Re-usable Metal Containers for Jet Engines

BCV - 9M Power Supply (AGE)

PLAT (Pilot's Landing Aid, Television)

VHF Transmitter AN/GRT - 3 & 3A

Relay Armature

PRC-25 - Man Pack Radio

VRC-12 - Vehicular Radio

GRC-50 - Combat Area Microwave Transmitter/Receiver

GVR-10 Geocentric Vertical Reference System

Model 5103R Bombing and Attitude Reference System

AN/AJB-3A Attitude Reference and Bombing Computer Set

Model 4005 G Attitude Indicator

Model 5404G Indicator Amplifier

Model 5808E Bomb Release Computer

Model 4060P Attitude Indicator

MD-1 Vertical Gyroscope

MC-1 Switching Rate Gyroscope

Model 1903A Rate Integrating Gyroscope

Model 2171W and 2171AB Gyroscopes

Navy Phase II VGI System

    Displacement Gyroscope - FSN VQ6615-020-9327-VGCY

    Attitude Indicator - FSN VQ6610-020-9328-VJDN

    Attitude Indicator - FSN VH6610-061-7882-VJGS

EXHIBIT 4
Page 3

Rate Gyroscope - FSN VQ6615-855-3857-VGCZ

Shockmount

ARV-2B/A Attitude Indicator

MG-1A Central Air Data Computer

ECK-7/A24G Central Air Data Compensator

ECK-8/A24G Central Air Data Converter

AVU-1/A24G-6 Mach-Airspeed Indicator

ASK-5/A24G-6 Mach-Airspeed Indicator Amplifier

AAV-1/A24G-7 Attitude-Vertical Speed Indicator

ASK-6/A24G-7 Attitude-Vertical Speed Indicator Amplifier

AF/A24J-1 Horizontal Situation Indicator

CPU-4/A Flight Director Computer

AF/A24G-1 Two Gyro Control

AF/A24G-1 Power Supply Amplifier

AF/A24G-1 Compass Adaptor

AF/A24G-1 Compass Controller

ECK-10/A24G-1 Third Gimbal Controller

ARV-2A/A Attitude Director Indicator

TRV-2/A Transmitter Rate Gyro

APPENDIX

CORRECTIVE AND PREVENTIVE MAINTENANCE COST

The Nature and Importance of Maintenance Cost--

Definition - MIL-STD-778 defines maintenance as:

"All actions necessary for retaining an item in, or restoring it to a serviceable condition. Maintenance includes servicing, repair, modification, modernization, overhaul, inspection, and condition determination."

The term "maintenance cost" will be used to refer to the cost of labor and material consumed in performance of these actions. At some points it will be useful to distinguish between corrective and preventive maintenance. As defined in MIL-STD-778, corrective maintenance is:

"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 the specified performance."

Preventive maintenance is:

"That maintenance performed to retain an item in satisfactory operational condition by providing systematic inspection, detection and prevention of incipient failure."

Magnitude[1] and Susceptibility to Change - There are approximately 950,000 persons directly engaged in DoD maintenance activities. Of this total, 675,000 are military personnel, 185,000 are GS civilians, and 90,000 are civilians on contract with the Government. At estimated costs of $6,000 per military

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[1] Estimates on magnitude of maintenance cost were obtained from the Directorate for Maintenance Policy, OASD(I&L).

man-year and $10,210 per civilian man-year, the annual cost of maintenance manpower is $6,857,750,000.

In the aggregate, the annual cost of maintenance manpower has approximately equalled that of maintenance material over the past few years. On that basis, the total cost of maintenance manpower and material currently runs about $13.7 billion annually. This figure does not include the cost of non-maintenance activities required to support maintenance (e.g., parts supply, maintenance training, and transportation of material to and from maintenance activities).

The magnitude of maintenance cost is further indicated by consideration of individual types of reparable equipment. In every type reviewed, it was observed or reported that most items had life cycle maintenance costs amounting to a large percentage of their purchase prices. In the area of electronics, this percentage seemed particularly high. One report,[1] for example, listed military electronics equipment as having annual maintenance cost ranging from 60 to 1000 percent of its original procurement cost. This report referred to Air Force studies indicating that annual maintenance cost of electronic equipment varies from 3 to 29 times original equipment cost, and to a BuShips article stating that active life maintenance cost of electronics equipment ranges from 7 to 100 times original equipment cost. Another report[2] investigated maintenance

[1] E.F. Dertinger, Funding Reliability Programs, A report prepared by the Product Assurance Manager of the Equipment Division (Waltham, Massachusetts: Available from Mr. Dertinger, The Raytheon Company).

[2] H. Dean Voegtlen, The Cost of Unreliability to the Air Force During Operation and Maintenance, A report prepared by the Manager, Product Effectiveness, Ballistics Systems Division of the Aerospace Group, (Los Angeles: Available from Mr. Voegtlen, Hughes Aircraft Company).

cost on three Air Force equipments--a ground-based search radar,
a navigational aid, and a UHF communications equipment. The
ratio of _annual_ maintenance manpower and material cost to origi-
nal equipment cost was 0.6 for the radar, 12 for the navigational
aid, and 6 for the communications equipment.

Maintenance cost is, therefore, a very prominent part of
total logistics cost and very significant relative to purchase
price for most reparable items. In addition, experience has
made it clear that the frequency and cost of maintenance actions
can vary significantly among different suppliers' equipments
produced to essentially the same specification. Such variance
naturally increases as the specification becomes less detailed.
It is widely recognized as being present in procurements based
on performance (form, fit and function) specifications. Pro-
ject fieldwork revealed that it is also a factor in large numbers
of procurements, the specifications of which are referred to
as detailed.

Procurements cannot be meaningfully grouped into the two
categories, _performance_ and _detailed_. A large percentage do
not fall cleanly into either class. Often drawings are used
which only partially detail the item to be purchased. Many
times, for example, they impose envelope and performance re-
strictions on subassemblies but do not spell out their internal
makeup. Design changes are permitted and can cause changes in
maintenance cost of the equipment. Therefore, it cannot be
inferred from mere use of the term "detailed specification" in
a procurement that a maintenance cost calculation is unneces-
sary.

A primary reason why maintenance cost among different sup-
pliers' equipments (made to the same specification) can vary

significantly is that it is not uncommon for frequency of corrective maintenance actions required on an equipment to differ very substantially among the various bidders' versions. While most cost-influencing factors tend to change in relatively small increments, it is not rare for failure frequency to undergo an order of magnitude change. In the course of the project, numerous cases have been reviewed in which the failure frequency of one supplier's equipment was several times that of another supplier's.

The sensitivity to changes in supplier, combined with the amount of money involved, makes maintenance cost the most important logistics cost category to consider in the procurement decision process.

Relationship to Total Cost - To examine the way in which changes affecting maintenance cost influence total cost (purchase price plus total support and operating costs), it is convenient to employ a simplified model. Suppose we let:

I = unit initial cost of the end item, including purchase price, transportation, support equipment, initial training, documentation, FSN introduction, initial filling of the parts pipeline (to provide for maintenance turnaround time only), and buying costs.

L = service life of the end item.

M_{ic} = mean time between failures (MTBF) for the i-th part.

C_{ic} = mean cost of a corrective maintenance action resulting from failure of the i-th part.

M_{ip} = mean time between preventive maintenance actions on the i-th part.

C_{ip} = mean cost of a preventive maintenance action on the i-th part.

n = number of parts in the end item.

T = total cost of the end item over its service life.

Then,

$$T = I + \sum_{i=1}^{n} \left(\frac{L}{M_{ic}} - 1 \right) C_{ic} + \sum_{i=1}^{n} \left(\frac{L}{M_{ip}} - 1 \right) C_{ip}.$$

The model is simplified because it neglects operating costs as well as continuing support costs other than those for maintenance material and labor. Such exclusion is not critical, however, because the purpose of the model is to exhibit the change in total cost induced by changes in M_{ic}, C_{ic}, M_{ip}, and C_{ip}; and these elements will generally not produce differences of any magnitude in the costs omitted.

The model can be further simplified without hampering its purpose. If we let

   M = mean time between consecutive maintenance actions
       (not necessarily of the same type or relating to
       the same part);

   C = mean cost of a maintenance action (of any type, re-
       lating to any part);

and I, L, and T be the same as before;
then the equation becomes

$$T = I + \left(\frac{L}{M} - 1 \right) C. \tag{1}$$

Next, let us consider changes in frequency of maintenance, cost of a maintenance action, and initial cost, resulting possibly in a change in total cost. We may represent these changes by ΔM, ΔC, ΔI, and ΔT, respectively; and the resulting equation is

$$T + \Delta T = I + \Delta I + \left(\frac{L}{M + \Delta M} - 1 \right) (C + \Delta C). \tag{2}$$

To solve for the change in total cost we subtract equation (1) from equation (2) yielding:

$$\Delta T = \Delta I + \left(\frac{L}{M+\Delta M} - 1 \right) (C + \Delta C) - \left(\frac{L}{M} - 1 \right) C$$

$$= \Delta I + \frac{LC + L\Delta C}{M+\Delta M} - C - \Delta C - \frac{LC}{M} + C$$

$$= \Delta I - \Delta C + \frac{MLC + ML\Delta C - MLC - \Delta MLC}{M(M+\Delta M)}$$

$$= \Delta I - \Delta C + \frac{L(M\Delta C - \Delta MC)}{M(M+\Delta M)} \ .$$

That portion of the total cost change resulting directly from changes in frequency and cost of maintenance actions will be designated by ΔT_m and equals:

$$- \Delta C + \frac{L(M\Delta C - \Delta MC)}{M(M+\Delta M)} \ .$$

The purpose of our logistics cost analysis is, of course, to see whether $-\Delta T_m$ is greater or less than ΔI. The net change is to the advantage of the Government only if $-\Delta T_m$ is greater than ΔI; i.e., if

$$\Delta C - \frac{L(M\Delta C - \Delta MC)}{M(M+\Delta M)} > \Delta I.$$

Suppose the Government is procuring a quantity item whose estimated service life (L) is 5000 hours. Supplier A's version is evaluated as having a mean time between maintenance actions (M) of 50 hours and mean cost of a maintenance action (C) of $30. Supplier B's version is evaluated as allowing 20 additional hours between maintenance actions (ΔM), but an additional cost per maintenance action (ΔC) of $5. Then

$$-\Delta T_m = +5 - \frac{5000(50 \cdot 5 - 20 \cdot 30)}{50(50 + 20)}$$

$$= +505.$$

This calculation tells us that it is to the economic advantage of the Government to buy supplier A's product only if its unit initial cost is at least $505 less than supplier B's product.

Suppose the circumstances of the procurement were the same except that supplier B's version had a mean time between maintenance actions greater than supplier A's by 6 hours instead of 20 hours. Then

$$-\Delta T_m = +5 - \frac{5000(50 \cdot 5 - 6 \cdot 30)}{50(50+20)}$$

$$= -95.$$

This result means that it is to the economic advantage of the Government to buy supplier A's product unless its unit initial cost is at least $95 more than supplier B's.

Figure 1 uses the relationship $T_m = \left|\frac{L}{M} - 1\right| C$, where T_m is total maintenance cost, to illustrate the varying sensitivity of maintenance cost to changes in mean time between maintenance actions (M) for different levels of M. Hypothetical service life of 5000 hours is used in the example.

Elements of Maintenance Cost--A large number of elements influence the maintenance cost of an equipment and, therefore must be known in order to calculate it in advance. The major elements will be listed here. Brief comments will be made regarding the source of required information regarding each element.

Operating Environment - The range of conditions in which the equipment must operate within specifications prescribed must be stated clearly by the Government in the RFP. If demonstration of the equipment's maintenance characteristics is required, test conditions must be stated precisely. Such statement is necessary whether the test is physical or simulated, and whether the test environment is artificial or real.

Figure 1:   SENSITIVITY OF MAINTENANCE COST

T_m = Total Maintenance Cost $= \left(\frac{L}{M} - 1\right) C$

    L = Service Life = 5000 hours
    M = Mean Time Between Maintenance Actions (hours)
    C = Average Cost of a Maintenance Action ($)

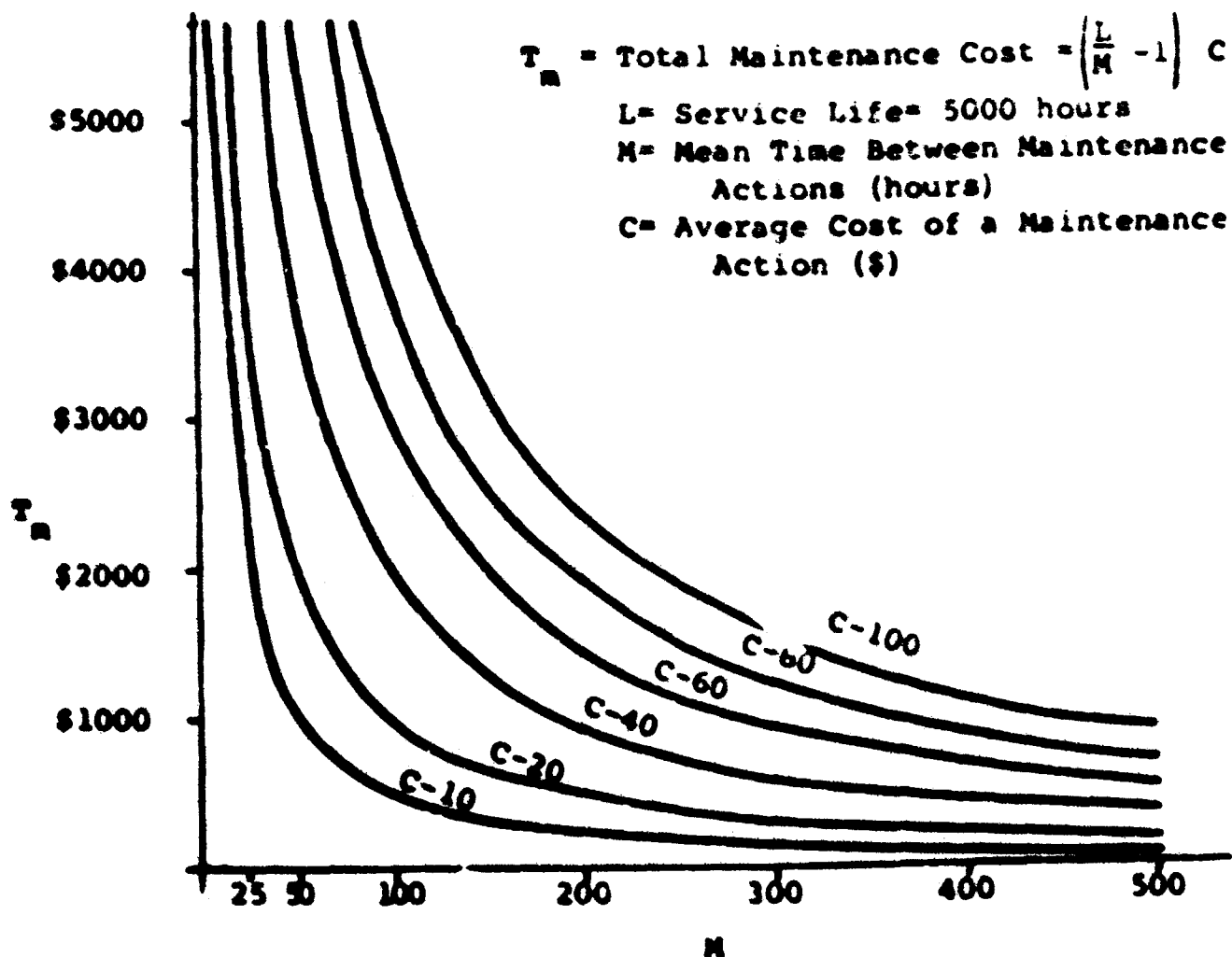| M	T_m					
500	90	180	360	540	720	900
400	115	230	460	690	920	1,150
300	156	312	624	936	1,248	1,560
200	240	480	960	1,440	1,920	2,400
100	490	980	1,960	2,940	3,920	4,900
50	990	1,980	3,960	5,940	7,920	9,900
25	1,990	3,980	7,960	11,940	15,920	19,900
	C = 10	C = 20	C = 40	C = 60	C = 80	C = 100

T_m = Total Maintenance Cost $= \left(\frac{L}{M} - 1\right) C$

    L = Service Life = 5000 hours
    M = Mean Time Between Maintenance
        Actions (hours)
    C = Average Cost of a Maintenance
        Action ($)

Equipment Design - As was pointed out in "Design Information Impediments," the procurement situations being considered are those which allow discretion to the bidders in design of their equipments. Estimation of maintenance cost, like several other logistics costs previously discussed, presupposes availability of detailed design information--not to the point of parts identification by number and supplier, but to a far greater extent than is the current practice. Such information can only be supplied by the bidders.

Service Life - The equipment specification should establish a minimum acceptable service life, which may be stated in such terms as months, operating hours, or miles. The government may also stipulate the maximum service life allowable for use in calculating maintenance cost. Such a maximum will generally be desirable, because the need for most equipments is not forecast to extend for an unlimited duration. If the minimum and maximum figures are not the same, each bidder must state at what point within the allowable range the service life of his equipment falls. His preventive maintenance plan and reliability evaluation (to be discussed) must naturally be consistent with the service life stated.

Parts Failure Rates - The government must explain in the RFP how failure rates are to be obtained for use in any estimation of maintenance cost. The government must assume this responsibility no matter which party performs the failure frequency calculations. Many possibilities exist as data sources: e.g., standard failure rate tables, standard prediction techniques, actual data from past experience, special testing, and contractor warranty figures. Failure rates will be treated in greater detail under "Reliability."

Parts Costs - Unit costs of maintenance material are
an important factor in computing maintenance cost. Two key
sources for unit costs of parts are the bidders' proposed prices
for initial spares, and parts catalogs. The securing of parts
information with the bid is discussed elsewhere in the report.
Whenever practical, it is desirable to avoid detailed treatment
of parts cost by using cost standards, such as average material
cost of a repair or the overall ratio of material cost to labor
cost. Variance of such factors among items is so great, however,
and factors valid for individual items are so difficult to ob-
tain, that unit parts costs (to be used with frequencies of need)
will often be the most appropriate approach.

Skills - The Government should indicate in the RFP, as
part of the maintenance plan, those skill levels which the bid-
ders may assume to be available for maintenance of the equipment.
Any additional or special skill requirements must be identified
by the bidder. The government should estimate the increase in
cost (e.g., training or transportation cost) imposed by these
requirements. (Costing of this sort is covered under other cate-
gories in this report.) The cost increase should be added to
the bidder's end item price in evaluation of his proposal.

Maintenance Manhours - The Government must describe
in the RFP any techniques or procedures which are to be used in
establishing the maintenance manpower demands of the equipment.
It must state precisely the extent to which the bidders must
furnish design information with their bids, as well as those parts
of the manpower evaluations they will be expected to participate
in. Any standard factors to be employed must be identified by
the Government. On occasion (especially for commercial items)
the Government may require that sample equipments be made available

for physical test prior to contract award. Maintenance manpower requirement prediction will be discussed more fully under "Maintainability."

Manpower Cost Rates - The Government must specify the manpower cost rates to be used in any calculation of maintenance cost, except for maintenance manpower to be supplied by the contractor. Extent of contractor maintenance should be clearly defined by the combination of government specification and contractor bid, and the price of manpower for such maintenance should be required as part of the bid. For government manpower, it will sometimes be satisfactory to use cost standards for categories of repair, service and overhaul on a "per job" basis, rather than applying hourly rates to estimates of manhours required. "Per job" standards, where data are available to support them, will substantially simplify the maintenance cost calculation. Total cost of manpower for maintenance should naturally be considered in evaluation of bids.

Preventive Maintenance Plan - Each bidder must be required to provide a program of preventive maintenance actions, consistent with the Government's maintenance plan, upon which the maintenance and performance claims in his bid are based.[1]

Maintenance Tools and Fixtures - The Government should indicate in the RFP, as part of the maintenance plan, the level of tooling and fixtures which the bidders may assume is available for maintenance of the equipment. Any additional or special requirements must be identified by the bidders. They should be required to quote on special tooling and fixtures, and the prices so obtained should be added to their end item prices in evaluation of their proposals.

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[1] This program should be written into the contract as defining adequate preventive maintenance for the equipment.

Transportation Cost - If the combination of unit ship-
ping rate, distance to repair, service, or overhaul facilities,
and probable frequency of need for these facilities is such that
maintenance transportation cost is likely to be substantial and
vary significantly among the bidders, such cost should be con-
sidered in bid evaluation. The Government should make the cal-
culations, using transportation cost standards. Inputs from
several other parts of the logistics cost analysis will be essen-
tial. The maintenance and operating plans stated in the RFP
must be sufficiently well-defined to indicate what distances will
be involved. Inputs on failure rates and the preventive mainte-
nance schedule have already been mentioned. The bidders must
supply minimum shipping weights, dimensions, and requirements
for packaging and other preparations with their bids. Since
these data are frequently necessary for computing cost of trans-
portation from place of production to place of initial storage
or use, their need for calculation of maintenance cost may not
constitute an additional information requirement on the bidders.

Administrative, Supply, and Training Overhead - Since
major parts of the administrative, supply, and training functions
are for support of maintenance activities, these functions are
often treated partly as maintenance overhead costs. In logistics
cost analysis for procurement, however, we are interested in
cost differences among equipments of different suppliers.
Applying an overhead rate to some base would infer that the costs
covered by that rate vary in direct proportion to the base. For
item by item analyses, we can find no base in maintenance for
which such treatment can be justified. Therefore, supply and
training costs for support of maintenance are covered more
directly under the Inventory Management and Training (Maintenance

and Operational) categories, respectively. Administrative costs
of maintenance (consisting primarily of the local clerical func-
tions required) vary with the number of maintenance transactions
rather than with such factors as the manpower cost of repair or
the purchase price. If administrative cost differences among
different suppliers' products are likely to be significant, they
should be computed through use of government cost standards, on
a "per repair" or "per maintenance action" basis. Failure rates
and possibly the preventive maintenance schedule are prerequisite
data.

Cost of Maintenance Downtime - In addition to the man-
power and material costs of service, repair, overhaul, and
replacement of equipment. maintenance involves equipment down-
time--perhaps only for the item repaired, but perhaps for a
larger equipment of which the item in question is a subassembly
or part. A value may be assigned to the readiness (or lack
thereof) of the equipment during such time. Cost of downtime
will be discussed briefly under "Availability," but this pro-
ject does not undertake to deal with methods for establishing
the value of having the equipment "up," or, conversely, for
assigning a cost to having the equipment "down."

From the above list of maintenance cost elements, it can
be seen that the two most complicated questions to answer in
estimation of maintenance cost are: (1) How frequently will
the various maintenance actions be required? and (2) How long
will the various maintenance actions take, and how much man-
power will they consume? For meaningful consideration of
logistics costs in procurement, we must be able to answer these
during the bid evaluation process and prior to actual field ex-
perience with the equipment. The methods for handling the

questions must be rigorously established in any procurement by
the time the RFP is released. Techniques and measures employed
must be objective.

The first question will be considered under "Reliability";
the second will be addressed under "Maintainability."

Reliability--

Definition and Introduction - MIL-STD-721A defines
reliability as: "The probability that materiel will perform its
intended function for a specified period under stated conditions."
Thus the three factors to be considered in reliability deter-
mination are the end item's functional requirements, a duration
of time in which these requirements will not be violated, and
the probability that such achievement can be anticipated. It
is not necessary for our purposes to treat all three factors as
independent variables. We can assume functional requirements as
fixed. We can also select a specific probability level at which
all bidders' products will be evaluated. Then we need only to
measure the time period during which the equipment will, with
the stated probability, meet its functional requirements. For
convenience of explanation, we shall tend to use the fifty per-
cent probability level and speak in terms of mean time between
failure (MTBF) and mean time between maintenance actions (MTBM).
Other probability levels can conveniently be used in practice.

It is important to note that the term "reliability" is
used in the sense of inherent reliability of the equipment.
Manufacturing errors, human errors in operation, handling damage,
and other such problems which do not arise from the equipment
itself are not included in our definition. Quality control in
manufacturing is likewise not included in our discussion. It is
covered separately by specifications and inspection procedures.

No exclusions are made, however, regarding failures requiring certain levels of corrective maintenance. Wherever possible and significant, repairs to be rendered locally are considered as well as those necessitating work which must be performed by more specialized, better equipped, often remote maintenance organizations, both government and contractor.

Failures fall generally into three categories, initial, wearout, and random. Initial failures are those arising because the equipment was not right to begin with. Wearout failures are those whose occurrence can be predicted fairly accurately because the variance about the mean time of occurrence is small. Thus, wearout failures can often be anticipated and prevented by scheduled maintenance replacements or overhauls. Random failures are those which cannot be predicted with sufficient accuracy to be economically eliminated by preventive maintenance. Initial and wearout failures which occur so infrequently that their patterns are not recognized are treated as random. The assumption of randomness can often be justified by the heterogeneity of the failures included in the random category.

Reliability evaluation for the purpose of maintenance cost estimation will be considered for each of the three failure types. The state-of-the-art will be indicated primarily by brief descriptions of a few of the different types of techniques available.

Initial Failure - Initial failures include those cases in which the item does not perform adequately from the start, as well as cases of early failure in which it is indicated that the item had not been satisfactory from the beginning. Such failures are most apt to happen with items from the first part of a production run, especially with a new supplier, when the production

process still needs improvement. For some equipments having a
large number of parts, initial failures are routinely antici-
pated if the producer has not previously supplied the item and
his design or some of the parts used differ from the previous
of any) producer's. MIL-STD-72 A recognizes this situation in
including a definition of debugging:

> "A process of 'shake-down operation' of each
> finished materiel which is performed prior
> to placing it in use in order to exclude the
> early failure period. During debugging 'weak'
> elements are expected to fail and be replaced by
> elements of normal quality which are not sub-
> ject to early failure."

Early failure period is defined as:

> "That period of materiel life starting just
> after final assembly where failures occur
> initially at a higher than normal rate due
> to the presence of defective parts or ab-
> normal operating procedures."

When one or more bidders' products will require debugging in-
volving expense (not included in the bid price) to the Govern-
ment, and another bidder is offering a debugged item, then the
anticipated debugging expense should be added to the bid price
for purposes of evaluation.

On relatively complex equipments which are reprocured
many times, maintenance data may justify the use of learning
curves for failure rates or maintenance cost. It has often
been suggested that when particular producers have habitually
had experience with initial failure on early production, the
cost of such experience might be estimated for use in bid evalua-
tion. Such estimates, however, would be very difficult to justify.
Since it cannot be established that the same pattern of performance

will be repeated in the procurement at hand, the past records
of the bidders should more appropriately be considered in the
evaluation of their technical qualifications as a part of source
selection.

Initial failures cannot be anticipated on individual items.
They can be predicted only in total. Therefore, maintenance
cost calculations should attempt to disregard early failures
which can be eliminated (except when debugging expense or use
of learning curves is justified) and should treat others as
random. They could theoretically be treated as random at spe-
cial rates for the early period of use, but separate failure
rates for that period are not likely to be available. Thus we
shall be concerned with random and wearout failures much more
than with initial failures.

Random Failure - If a certain type of failure of an
equipment has random occurrence, we cannot predict when it will
happen. Such a failure has very low probability of occurrence
in any specific small period of its life. This is not to say,
though, that we have no knowledge of what the failure experience
will be. We are very likely to have a good estimate of the mean
rate of the failure. This rate will not enable us to say with
confidence at what points in the life of the equipment such
failure may be expected, but it will permit us to calculate fair-
ly accurately, for a long period or for many end items, the
total number of failures that will occur. Even when the end
items are few and the time period abbreviated, the involvement
of many different types of random failures will permit failure
calculation which has a high probability of being close to the
actual number of failures in total. Random failures can occur
in almost every type of equipment, but are highly predominant in
electronic items.

MIL-STD-756A presents a generalized reliability prediction procedure based on the premise that end item failure characteristics can be inferred from part failure experience. The standard deals with drawing a reliability block diagram, developing equations representing reliability of the various blocks and of the total product, stating assumptions and simplifications, listing parts for each block, obtaining failure rates, adjusting failure rates by government-specified environmental factors, calculating block reliability, and calculating product reliability.

This approach comprises the Part Failure Method. It is a very convenient and appropriate method when design information can be obtained and when part failure rates can be considered constant over time. Then the exponential distribution may be used and combination of probabilities is simple. When part failures are not constant over time, the method becomes more complicated but is often still practical. It may be satisfactory to treat the failure rates as constant over discrete subperiods so that the difficulties of combining changing rates are minimized.

MIL-STD-756A specifies MIL-HDBK-217 as the data source for failure rates of electronic parts and requires substantiation of all rates not obtainable from this handbook. The standard lists specific multipliers for adjusting failure rates according to environment.

Another approach to reliability prediction is the Active Element Group (AEG) concept. This concept is of particular interest because it does not assume finely detailed knowledge of the hardware under consideration. NAVWEPS 00-65-502 presents a procedure for use of the AEG concept when insufficient data can be obtained for employment of the Part Failure Method.

The AEG was selected as the smallest functional block that could be considered short of tying-in to specific parts and fine details of design. An _active element_ is defined to be a device which controls or converts energy. An AEG consists of one active element and a number of passive elements which perform a specific function. Transistors, electron tubes, combustion chambers, and pumps are examples of active elements. Two examples (from NAVWEPS 00-65-502) of AEG s are: (1) a transistor and several resistors and capacitors; (2) a relay, its solenoid, and from two to ten circuit contacts.

Plots of the number of AEG's in various equipments against MTBF's calculated by the method of MIL-STD-756A with failure rates from MIL-HDBK 217 have indicated good correlation. For many electronic equipments graphs are available from which (either directly or through equations of the exhibited relationships) AEG counts or estimates can be converted to MTBF estimates. With assumption of exponential failure distributions, the MTBF's can be converted into failure rates or probabilities of failure-free operation for specific lengths of time.

The AEG procedure of NAVWEPS 00-65-502 employs reliability block diagrams and mathematical models, but does not require that these be so detailed as those in the Part Failure Method. The diagrams and models are structured so that reliability estimates can be attained for each functional block as well as for the equipment as a whole. In contrast to the Part Failure Method, the AEG approach leaves to the option of the user the degree to which (if at all) the evaluation will extend below the block level. Such design features as application of redundancy or unique devices at the lower levels could, however, make it highly advisable to undertake more than the minimum

analysis in particular cases. Significant differences in repair
costs for different type failures of the same functional block
could also force added detail into the calculation.

The ABG approach shows considerable promise, but many more
correlation studies are needed to find the range of equipments
over which its results are sufficiently accurate. Its unique
feature of providing reliability estimates without minutely de-
tailed design data is encouraging, but will be of little value
for our purposes unless the other parts of a logistics cost
analysis can also be made without this detail.

The RADC Reliability Notebook is another valuable source
of information. It is composed primarily of parts reliability
factors which may be used in application of the Part Failure
Method, but also contains sections on the mathematics of relia-
bility prediction, testing for reliability, and reliability
factors in design. The Notebook adds to the sophistication of
the Part Failure Method by including allowance for the effect of
stress factors on the failure rate of each part considered.
Supporting parts failure rates are presented as functions of
electrical and thermal stresses, according more realism to the
input and the model of the reliability evaluation.

Another prediction technique described by the RADC Relia-
bility Notebook is the BuShips Procedure, which employs a
"severity of application" index in evaluating electronic equip-
ment. Various severity categories are defined, based on the
ratios of voltage and current to rated values, and the ratio of
power dissipation to rated value. Severity ratings and numbers
of applications of the different type parts permit selection
of the numbers of failures per 5000 operating hours from a set

of curves developed by the Vitro Corporation of America. For
each type part, the number of failures so obtained is multiplied
by an empirical factor of 1.2 for adjustments and mechanical
failures. The resulting figure is divided into 5000 to get the
MTBF.

The simplest reliability prediction technique is the Parts
Count Method. Its use presumes knowledge of equipment design.
Average failure rates for classes of parts, such as transistors,
switches, transformers and coils, or blowers and motors, are
multiplied by the numbers of applications; and then the results
are added to get the end item failure rate, the reciprocal of
which is the MTBF. This method does not produce as accurate an
MTBF as the more detailed procedures, but it is very likely to
provide a good estimate of the relationship among the relia-
bilities of equipments of the same type, and it is inexpensive
to apply. Average failure rates for such a method may also be
found in the RADC Reliability Notebook.

MIL-HDBK 217 has already been mentioned as a source of
parts failure rates and is probably the most widely used docu-
ment for this purpose, although many others have been developed
by various contractors and are successfully used in equipment
design. The Handbook has considerable overlap with the RADC
Reliability Notebook and is based exclusively on the Part Failure
Method, as is clearly indicated by its opening statements:

>"After all other factors are taken
>into account, and after the best experience
>of the designer has been brought into
>play, the ultimate reliability of com-
>plex electronic equipment depends upon
>the reliability of the parts built into
>that equipment.

in estimating maintenance cost. The need for specific wearout repairs and replacements can be anticipated at definite intervals in an equipment's life, provided the operating conditions are known. Thus these maintenance actions can be regarded as scheduled actions in establishment of a maintenance cost estimate. Many of the actions will, in fact, be performed on a scheduled basis, for the predictability of their need often makes it economically advantageous to perform them according to a fixed plan rather than on an unscheduled basis as they arise.

Wearout failures are prevalent in mechanical items. They are dependent primarily on the design of the equipment, the properties of the materials used, and the operating conditions.

There are six key wearout failure types. Stress rupture results simply from constant conditions of load and temperature over a period of time. Corrosion is deterioration of metal by chemical or electrochemical action. Fatigue is caused by repeated or fluctuating stress less than the tensile strength. Impact results from sudden application of a moving load. Thermal failure is deterioration by melting, vaporization, decomposition, and welding as a result of high temperatures. Finally, wear is the removal of material from a solid surface caused by mechanical action. The wearout failure type regarded as the most important in mechanical and electromechanical equipments is wear. In fact, the major problem may be stated in a narrower sense as fatigue wear, a sub-category of wear characterized by repeated loading and unloading contributing heavily to the failure rate.

Part failure rates are available for items from many sources, and are generally given in terms of type of material, type of contact, and load conditions.

> "No matter how good the individual
> parts, the more of them built into the
> equipment, the poorer will be the re-
> liability of the equipment as a whole.
> Very complex equipment with hundreds or
> thousands of parts, requires a very high
> order of individual part reliability.
>
> "Any advance estimate of overall
> reliability must, therefore, be deter-
> mined by a knowledge of the reliability
> of the parts."

For many of the failure rates presented by MIL-HDBK 217,
adjustment factors are also given. These are based in most
cases upon such elements as ohmic or capacitance value, type
of insulation, or part rating. For relays and switches, how-
ever, the adjustment factors provided depend upon manufacturer,
designer, and user.

It can be seen from the above account that reliability
prediction for randomly failing items is highly developed.
Additional research is expected to be very helpful, especially
in combination of failure rates, but the tools at hand are suf-
ficient to support meaningful and effective reliability evaluation.

If bidders can be expected to know the basic designs of
their equipments, they can be expected to carry out reliability
evaluations according to well-defined, established procedures.
Such procedures can be stipulated in the RFP and the reliabili-
ty evaluations can effectively be audited by the Government in
the process of selecting the successful bidder.

Wearout Failure - Since wearout failures are by defi-
nition those whose occurrence can be predicted on specific
items (i.e., those having small variance about their mean time
of occurrence), they are handled differently from random failures

Tests of short duration are sometimes feasible for failure rate establishment because wear can usually be measured. Measurements of wear over a short period can be extrapolated to determine the point in time when replacement or repair would be necessary. For determining failure rates, extrapolation from short term tests under normal conditions is generally more accurate than accelerated tests to failure under artificially severe conditions. Block diagrams and equations for combination of rates are essential features of a wearout analysis,[1] just as they are in the case of random failure.

From the wearout analysis it can be established that certain maintenance actions must be performed no later than at certain times. These times can be fixed and the failures eliminated from further consideration. For many anticipated failures, it is desirable to schedule the repair or replacement considerably in advance, to take advantage of the economy which may result from substitution of one larger maintenance action for two or more smaller ones.

The Government may require wearout failures to be evaluated by the contractor in accordance with an established procedure. It is prabably most practical to require the result in the form of a schedule of repairs and replacements for items having wearout characteristics. Requirements for all such evaluations must be clearly defined in the RFP and the techniques and procedures must be made subject to government audit.

In some cases, it may be practical and useful for the Government to require sample equipments for physical testing

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[1] RADC-TDR-64-50 is an example of a document containing both wearout failure rates and prediction techniques.

as part of the bid evaluation process. Such testing would be most likely for commercial items. When physical tests are employed, the methods of testing must still be clearly explained in the RFP.

Verification - Verification of the bidders' conformance with reliability analysis requirements for bid evaluation should not be confused with demonstration that the delivered equipment meets its technical specifications. They are independent and for separate purposes. Conformance with reliability evaluation requirements stated in the RFP simply entails the bidders' carrying out the evaluations in precisely the way the Government stipulated and including reports of the evaluations with their bids. It does not impose additional conditions on the equipment delivered, except as information presented with the bids is written into the contract.[1] Verification should be accomplished through government audit of the reliability reports accompanying the bids.

Maintainability--

Definitions and Introduction - MIL-STD-778 defines maintainability as:

> "a characteristic of design and installation which is expressed as the probability that an item will conform to specified conditions within a given period of time when maintenance action is performed in accordance with prescribed procedures and resources."

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[1] Incorporation of such data in the reliability specification of the contract is virtually useless unless coupled with valid demonstration procedures. Such procedures, since they have to do with the contract rather than the bid evaluation process, are not covered by this report. Adequate demonstration techniques are available, however, and are generally economically feasible provided the specified probability level of the tests is within reason.

Maintenance procedures are: "Established methods for periodic
checking and servicing items to prevent failure, or to effect
a repair." Maintenance resources are described as: "Facilities,
ground support equipment, manpower, spares, consumables, and
funds available to maintain and support an item in its opera-
tional environment."

As in the case of reliability, it is not necessary that we
emphasize the probability part of the definition. We may fix
the probability (for convenience at fifty per cent), assume the
specified conditions are known, and attempt to establish the
maintenance actions required.

Maintenance task is defined by MIL-STD-778 as: "Any ac-
tion or actions required to preclude the occurrence of a mal-
function or restore an equipment to satisfactory operating
condition." Maintenance tasks to be performed and their fre-
quency are provided by the failure identification and MTBF
techniques of reliability analysis. Parts requirements over
time also result from the reliability analysis when parts fail-
ure rates are employed. When less detailed reliability techniques
are used, a standard material cost of repair will probably have
to be prescribed by the Government. This standard could be the
average historical material cost of a repair for the type equip-
ment in question, a fixed percentage of the cost of the func-
tional block failing, or another figure of this nature. Special
tooling, facilities, and support equipment must be specified by
the bidders, after the Government has stated, in the mainte-
nance plan, the level of such DoD resources which can be assumed
available.

We are then left with the problem of establishing time

and manpower for carrying out the maintenance tasks. From these
and the above information, maintenance cost can be estimated.

There are eight key elements in maintenance task perform-
ance. Maintenance cost evaluation should be capable of covering
all of them, although not all eight occur on every task. The
elements are:

- preparation, disassembly, and assembly
- fault diagnosis and localization
- securing material
- fault correction (repair or replacement)
- cleaning and lubrication
- adjustment, realignment, and calibration
- checkout or final test
- preparation of reports

When maintenance time is measured or estimated for a task,
only six of these elements—all except securing material and
preparing reports—should be included. Government standards
should be made available for the excluded elements.

Prediction Techniques - The simplest way to obtain a
prediction of the man-hours required for corrective maintenance
is to calculate, from historical data on similar equipments,
the average man-hours per repair. This average can then be
multiplied by the number of predicted failures (obtained from
the reliability evaluation) over the expected service life of
the equipment. An analagous procedure can be followed for pre-
ventive maintenance actions, but it will usually be advantageous
to distinguish overhauls from other preventive actions because
of the large difference in cost. The average man-hours per
preventive action, exclusive of overhauls, can be multiplied by

the forecast number of such actions; and a corresponding multi-plication can be performed for overhauls. This type of simple calculation (which we shall call Method I) is advisable when the manpower cost of a maintenance action is not likely to vary, but substantial differences are expected in the reliabilities of the items evaluated. If man-hours per maintenance action are likely to be significantly different for the various items, how-ever, such calculation would fail to accomplish a primary objective of logistics cost analysis.

A more sophisticated handling of maintenance manpower (which we shall call Method II) would be to require the bidders to submit, for each maintenance action identified by the relia-bility evaluation, an estimate of man-hours needed to perform the six maintenance task elements cited above.[1] Maintenance could then be costed out at standard hourly manpower rates.

An entirely different type of maintainability prediction technique (to be called Method III) was developed by RCA[2] for electronic systems. The output of the technique is <u>active maintenance downtime</u>[3] rather than maintenance man-hours. Maintenance man-hours, however, have been shown by other studies to bear a relatively fixed mathematical relationship to active maintenance downtime on numerous electronic equipments.

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[1] Such a requirement is included in MIL-M-26512 (USAF).

[2] Reported in Volumes I and II of RADC-IDR-63-85.

[3] From MIL-STD-778: <u>Active maintenance time</u> is "the time during which preventive and corrective maintenance work is actually being done on the item." <u>Downtime</u> is "that portion of calendar time during which the item is not in condition to per-form its intended function."

Therefore, it is highly probable that the same type technique could be used for predicting maintenance man-hours.

In development of the RCA technique, a lengthy set of checklists was prepared. Scoring criteria were also set up and a fixed number of points was assigned to each statement on the list. Determining which statements correspond to the equipment being evaluated is a simple matter for someone who knows the design of the equipment, since the statements concern characteristics which can easily be observed from the design.

Various equipments whose active maintenance downtimes were known were scored by means of the checklists. In a regression analysis of checklist scores against downtimes, a good correlation was found to exist. As a result, a nomograph was developed for ready calculation of downtimes from the point totals. The procedure was then used for successful prediction of active maintenance downtimes for additional electronic systems.

Such a technique is not now available for prediction of maintenance man-hours in maintenance cost computation. Considering the extensive work which has been done in the areas of maintainability checklists and factors influencing maintainability (see, for example, ASD Technical Report 61-24), research on such techniques could be undertaken with high probability of achieving productive results within one year.

Verification - If historical maintenance man-hours (Method I) or techniques of the checklist-type (Method III) are employed, verification of a bidder's compliance with maintainability evaluation requirements of an RFP is simple. It

amounts to a check that the bidder followed the stipulated
rules rigorously in performing his analysis.

The currently limited state-of-the-art for procurement
evaluations, however, would make it necessary in many cases to
use maintenance man-hour estimates obtained from the bidders
(Method II). It would not usually be possible to check the
accuracy of these estimates during bid evaluation, so they
would have to be written into the contract specifications, accom-
panied by a demonstration procedure.

Such a procedure is outlined (although not for procure-
ment purposes) by MIL-M-26512C. After assigning maintenance
man-hours to tasks, a bidder groups together tasks which are
similar with respect to failure rate and maintenance man-hours.
He then determines an average failure rate and average mainte-
nance man-hours for each group. For each group he multiplies
the average failure rate by the average maintenance man-hours
per task by the number of tasks in the group. The resulting
number is then divided by the total of all such numbers to get
that group's percentage contribution to total maintenance man-
hour requirement of the end item.

This percentage will be used in drawing a sample of tasks
to be tested. First, however, the contractor must know the to-
tal size of the sample. He obtains this by using a statistical
formula (also presented by MIL-M-26512C). The Government must
provide the confidence and accuracy levels to be used in the
formula, while the contractor must enter the mean and standard
deviation of the estimated man-hours for the maintenance tasks.

The percentage contribution of each group of tasks is then
multiplied by the total sample size to yield the number of tasks

of that group which are to be tested. Once the equipment is available, the tests can be carried out wherever it is most advantageous. It would be desirable to have the tasks performed with government facilities, but if contractor personnel are to be used, the contractor's plant might provide a more economical arrangement.[1]

Availability--

Definition and Introduction - Availability is defined by MIL-STD-778 to be:

> "The probability that a system or equipment when used under stated conditions in an ideal support environment (i.e., available tools, parts, manpower, manuals, etc.) shall operate satisfactorily at any given time."[2]

Thus the concept has to do with uptime and downtime and the likelihood of being in an "up" state or a "down" state. Availability may be expressed as

$$A = \frac{MTBM}{MTBM + MTTR} .$$

where MTBM represents mean time between maintenance actions involving downtime, and MTTR stands for mean time to restore to operating condition (i.e., mean downtime).

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[1] Along with the demonstration procedure the contract should provide a penalty in the event the test outcome indicates the maintenance man-hours to exceed those estimated by the contractor. The percentage by which the total test man-hours are greater than the contractor's estimates for the tested tasks should be multiplied by the estimated total manpower cost used in the bid evaluation, to produce the amount by which the contract price will be reduced.

[2] The term "availability" used in this report is "achieved availability", distinct from "inherent availability" in that it includes preventive maintenance downtime, and distinct from "operational availability" in that it excludes supply and administrative downtime.

Since military equipment is usually bought for the purpose of achieving a certain level of readiness or effectiveness, effort is made to emphasize the composite effect of reliability and maintainability on readiness, and the concept of availability is employed. Figure 2 shows how different combinations of reliability and maintainability yield the same availability percentage. The rectangle in the lower left-hand part of the graph represents those reliability/maintainability combinations satisfying a specification in which minimum reliability and maintainability levels are stipulated separately. It should be noted that there are reliability/maintainability combinations outside the rectangle (i.e., in violation of the specification) having availability values greater than some of those inside. The advantage of availability specifications can thus easily be seen.

Figure 2:   AVAILABILITY (A) CURVES

No. of Interruptions of Operation for Maintenance
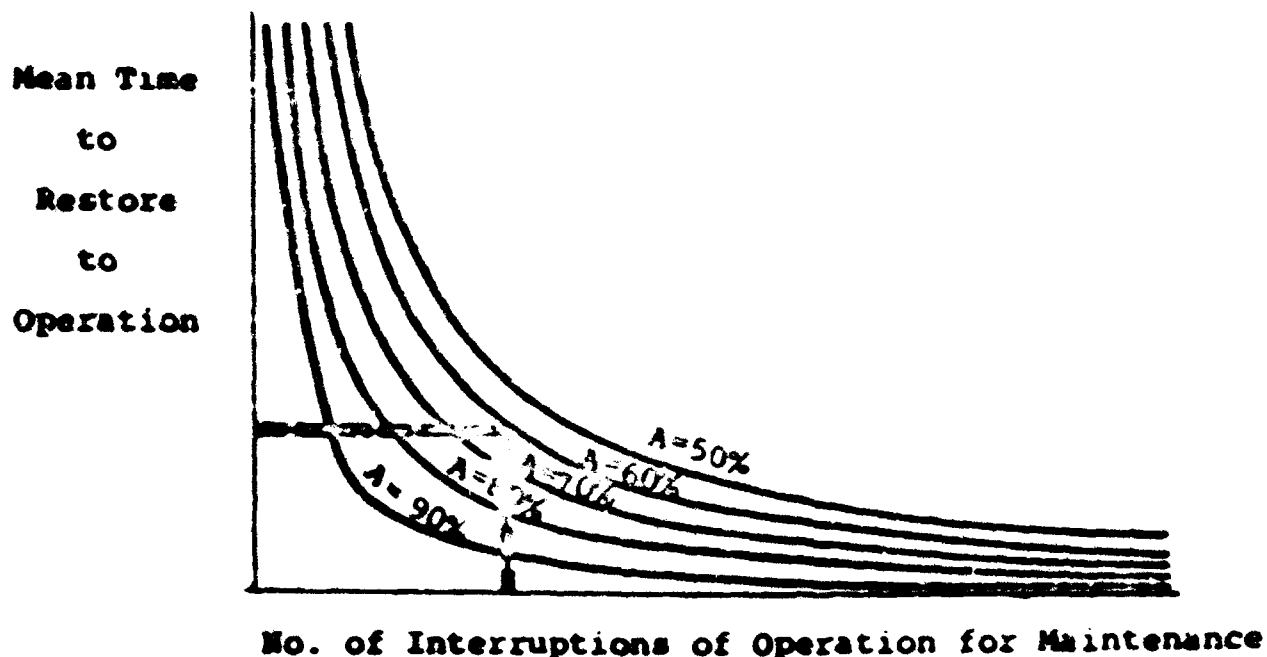
Use in Logistics Cost Analysis - From the above dis-
cussion it is apparent that availability is simply a mathe-
matical function of reliability and maintainability. Therefore,
no additional predictive techniques are required to deal with
it.

Availability must be calculated in a logistics cost analy-
sis (1) if the quantity of items can be varied in accordance
with the number required to achieve a specified readiness level,
or (2) if a value is assigned to downtime. However, our study
has not attempted to develop ways of handling either of these
situations. With respect to the first, it is our understanding
that the procurement quantity of equipments must be fixed in the
RFP. Regarding the second, evaluation of downtime in dollar
terms is a matter beyond the scope of our study and being
given extensive examination in numerous projects on costs and
measures of readiness and effectiveness.