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MILITARY HANDBOOK

SYSTEM ENGINEER'S DESIGN FOR DISCARD HANDBOOK

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FOREWORD

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3. This handbook was developed under the auspices of the US Army Materiel Command's Engineering Design Handbook Program, which is under the direction of the US Army Industrial Engineering Activity.

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LIST OF ABBREVIATIONS AND ACRONYMS

ABCA = American, British, Canadian, and Australian
AMC = US Army Materiel Command
AR = Army Regulation
ARL = Army Research Laboratory
ARO = Army Research Office
ASARC = Army System Acquisition Review Council
ATE = automatic test equipment
BCS = baseline comparison system
BDAR = battlefield damage assessment and repair
BIT = built-in test
BITE = built-in test equipment
CAD = computer-aided design
CAE = computer-aided engineering
CAM = computer-aided manufacturing
CDR = critical design review
COEA = cost and operational effectiveness analysis
CPAF = cost-plus-award fee
CPFF = cost-plus-fixed fee
CPIF = cost-plus-incentive fee
DA = Department of the Army
DFARS = DoD FAR Supplement
DoD = Department of Defense
DoDD = Department of Defense Directive
DoDI = Department of Defense Instruction
DS = direct support
DSU = direct support unit
DTC = design to cost
DTIC = Defense Technical Information Center
DTLCC = design to life cycle cost
DTOSC = design to operations and support cost
DTUPC = design to unit production cost
ECA = early comparability analysis
ECP = engineering change proposal
EEEL = Electronics and Electrical Laboratory
ESD = electrostatic damage
FAR = Federal Acquisition Regulation
FFP = firm-fixed price
FMECA = failure mode, effects, and criticality analysis
FMS = foreign military sales
FPI = fixed-price incentive
GS = general support
GSU = general support unit
HFE = human factors engineering
ILS = integrated logistic support
LCC = life cycle cost
LED = light-emitting diode
LOGAM = logistic analysis model
LORA = level of repair analysis
LRU = line-replaceable unit
LSA = logistic support analysis
LSAR = Logistic Support Analysis Record
MAC = maintenance allocation chart
MANPRINT = manpower and personnel integration
MATE = modular ATE
MICOM = US Army Missile Command
MOS = military occupational specialty
MPT = manpower, personnel, and training
MTTF = mean times to failure
NATO = North Atlantic Treaty Organization
NDI = nondevelopmental item
NIST = National Institute of Standards and Technology
NTIS = National Technical Information Service
O&M = operation and maintenance
O&S = operations and support
OSAMM = optimum supply and maintenance model
PC = printed circuit
PDR = preliminary design review
PEP = producibility engineering and planning
P3I = preplanned product improvement
PIP = product improvement program
PM = preventive maintenance
ppm = parts per million
QQPRI = qualitative and quantitative personnel requirements information
R&M = reliability and maintainability
RAM = reliability, availability, and maintainability
RCM = reliability-centered maintenance
RDEC = research, development, and engineering center
RDTE = research, development, test, and evaluation
RFP = request for proposals
RIW = reliability improvement warranty
SDR = system design review
SMR = source, maintenance, and recoverability
SOW = statement of work
SRU = shop-replaceable unit
SSEB = source selection evaluation board
STI = scientific and technological information
TDP = technical data package
TMDE = test, measurement, and diagnostic equipment
TOE = table of organization and equipment
TPS = test program set
TQM = total quality management
UPC = unit production cost
UUT = unit under test
VAST = versatile avionics shop tester
WSEIAC = Weapon System Effectiveness Industry Advisory Committee

PART ONE
GENERAL

Part One provides a perspective on this handbook and explains the reasoning behind the design for discard effort. The items, activities, and concepts that are affected by design for discard are summarized. Finally, the ways in which technology and research interact with design for discard are presented.

CHAPTER 1
INTRODUCTION

The purpose, theme, scope, and approach of this handbook are explained, and the contents of each chapter are very briefly summarized.

1-1 PURPOSE

The purpose of this handbook is to provide a reference guide on Army materiel design and the support philosophy known as "design for discard". The handbook provides design guidance as well as general information on applicable concepts, techniques, and procedures for practical implementation of a design for discard program. The handbook explains

1. What design for discard means
2. Why design for discard should be implemented
3. What the design for discard effort should involve
4. How to implement design for discard in a project
5. The tradeoffs involved during design
6. The interfaces with other system disciplines
7. The techniques used to evaluate the results of design for discard.

1-2 SCOPE

This handbook includes information on design for discard that is useful to the intended audience and is not otherwise conveniently available. Detailed engineering design and evaluation is beyond the scope of this handbook.

Additional information on specific engineering topics is readily available in Army documents and in the open literature, such as books, professional journals, trade magazines, advertising material, short courses, and conference and symposium proceedings. Appendix A lists some of the professional societies involved in such activities and some of the appropriate trade magazines.

The material covered in this handbook ranges from advocacy of design for discard through design and system considerations to program principles. The technical level of the material is appropriate to the intended audience. There is virtually no mathematics in this handbook although considerable reference is made to such material.

1-3 HANDBOOK OVERVIEW

The theme of this handbook is

1. When design for discard is added to a program, the process of analyzing the designs and products remains the same; only the outcome of the process is different. The outcome is different because engineers are putting different designs into the process and because management is using different criteria for "best".

2. That the Army should

   a. Strive to develop cost-effective maintenance and logistic support systems based on overall readiness affordability and wartime effectiveness rather than on peacetime economics.

   b. Let the commercial marketplace operate to reduce the peacetime cost of such systems wherever it can, insofar as such operation does not reduce wartime effectiveness.

   c. Define and implement the design for discard concept as the practical embodiment of the previous two points.

The approach of this handbook is to

1. Explain what design for discard is
2. Advocate the use of design for discard
3. Emphasize the crucial nature of diagnostics
4. Analyze the several ways of partitioning an item
5. Present hypothetical examples of design for discard
6. Consider the system implications of design for discard
7. Provide program perspectives.

The remainder of this chapter consists of a short summary of each of the subsequent chapters in this handbook.

Part One, "General", consists of Chapters 1 through 4 and gives the background of design for discard.

Chapter 2, "Philosophy of Design for Discard", and Chapter 3, "Advantages and Constraints", present the reasoning behind design for discard, advocate its use, and provide essential perspective on the process. They are written to be understandable to nontechnical as well as technical people. The cautions in both chapters are important; they concern the limitations of analytic techniques and the tradeoffs between long-term and short-term perspectives.

Chapter 4, "Technology Surveillance", shows how the Army interacts with research in Government, industry, and academe. It discusses the tradeoffs among using existing technology, using the state of the art, and pushing the state of the art.

Part Two, "Design Considerations", consists of Chapters 5 through 8 and shows the designer the kinds of decisions that must be made during the detailed design.

Chapter 5, "Diagnostics", introduces testing and testability as essential elements of design for discard and their application to several categories of technology.

Chapter 6, "Physical Arrangement", explains modular construction and then examines ways of partitioning an item into modules so that design for discard is feasible.

Chapter 7, "Material Selection", shows how traditional measures of value and ways of choosing materials for traditional repair are modified for design for discard. Also changes in outlook for the designer choosing materials for design for discard are explored.

Chapter 8, "Fabrication", illustrates how the choice of a fabrication technique is broadened when repairability is no longer important or even desirable. Producibility and productivity are reviewed.

Part Three, "System Considerations", consists of Chapters 9 through 14 and presents the management and technical elements necessary to integrate design for discard into the rest of the acquisition program.

Chapter 9, "Information Flow and Documentation", explains how design for discard information must be integrated with other information so that design for discard can be effective and monitored. The proliferation of various disciplines makes integration essential so as not to overwhelm the designers.

Chapter 10, "Analysis and Decision Techniques", explains the cost elements of logistic support and the various level of repair analyses that can be performed to minimize the overall cost of maintenance and logistic support. Although the computer programs for level of repair analysis are not given, their characteristics and importance to design for discard are listed and stressed.

Chapter 11, "Interface With R&M [reliability and maintainability] Engineering", and Chapter 12, "Interface With MANPRINT", explain the elements of reliability and maintainability and of manpower and personnel integration and show how each element must be considered in design for discard. A main objective of design for discard is to decrease the overall manpower needed while improving the reliability, maintainability, and safety of the system.

Chapter 13, "Effects on System Support", details the elements of system support that must be considered, viz, maintenance concept, integrated logistic support, logistic support analysis, inventory effects (short-term and long-term), replenishment of repair parts and components (vs initial purchases), and maintenance training and technical manuals. If design for discard is effective, these elements would be simplified, reduced, or eliminated.

Chapter 14, "Evaluation of Alternative Items", discusses the important practical aspects of comparing alternatives in design for discard, viz, evaluation criteria, quality assurance, configuration control, and design reviews. The consequences of the Army's changing its mind about using design for discard during a program are considered.

Part Four, "Program Considerations", consists of Chapters 15 through 17 and explains some of the prosaic, but important, aspects of the program, viz, control of costs, alternatives in acquisition, and elements of the contract.

Chapter 15, "Cost Control", introduces the design to cost program, emphasizes the life cycle cost, and concludes with an explanation of the producibility engineering and planning (PEP) program. Producibility is extremely important but tends to be overlooked by designers.

Chapter 16, "Acquisition Alternatives" presents the three major classes of such alternatives in descending order of the Army's preference, viz, product improvement, nondevelopmental item, and new development items. Design for discard can be effective in any of them.

Chapter 17, "Contractual Elements", summarizes the appropriate aspects of the Government regulations for acquisition and relates them to design for discard. A thorough understanding of these aspects will enhance the effective management of contractual design for discard efforts.

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CHAPTER 2
PHILOSOPHY OF DESIGN FOR DISCARD

The philosophy of design for discard is explained by providing a perspective on its nature, its limits, and the realism of its analytic models and by briefly discussing related concepts and activities, such as commonality, compatible modules, maintenance, design and manufacturing techniques and analyses, and interfaces with other engineering disciplines.

2-1 INTRODUCTION

This chapter explains the purpose, philosophy, and activities of the design for discard discipline.

2-1.1 BACKGROUND

Many products have components that are discarded when they cease to function properly. The decision about which components to repair and which to discard depends on economics, on available personnel skills, and on constraints such as those imposed by time, law, ethics, and safety. For example,

1. In the early 1900s many people straightened a bent nail rather than discard it because of the cost; currently, however, few people in this country would do that unless finding a new nail would take too much time.

2. In earlier decades a contaminated cleaning solution of chlorinated hydrocarbons was discarded; currently, however, the cost to discard it properly is so high that the solution would probably be purified and reused many times.

It is easy for engineers, managers, and legislators to view the costs of repairing an item too narrowly. This tendency is especially true of people who experienced the depression of the 1930s and the war of the 1940s. Thus "common practice" and "original cost of the part" are not complete reasons for selecting the level at which a part or assembly is to be discarded when it is not functioning properly. A disciplined approach is necessary for making such decisions initially and for maintaining a record of them.

2-1.2 DISCIPLINED APPROACH

There are three major elements of the disciplined approach to design for discard:

1. Management must provide the proper atmosphere for the design group first by removing the stigma from nonrepairable items and then encouraging the design group to broaden its knowledge and inventiveness to include creative designs for discard.

2. Management must develop and provide adequate tools for evaluating designs based on their suitability for discard. Such tools must be useful at all stages in the design process, especially in the early stages where important engineering judgments are made without much quantitative information.

3. Everyone must realize that successful design for discard is the inventiveness of the design engineering group in finding several appropriate ways to convert a function into hardware. There is no "by the numbers" routine for design for discard, and the temptation to produce such a routine must be avoided.

2-2 PERSPECTIVE

Discarding an expensive item can create a negative response in some people. Providing a clear, rational, realistic basis for design for discard without unduly limiting the concept requires an understanding of all the factors and perceptions involved.

2-2.1 NOMENCLATURE

There is a distinction among a replaceable unit, a discardable unit, and a nonrepairable unit. Replaceable merely means that the unit is (or can be) replaced as a whole. Examples of usage are line-replaceable units (LRUs), shop-replaceable units (SRUs), etc. Discardable is a special case of replaceable. Discardable refers to an economic and performance constraint, i.e., in the ordinary course of events, the unit should be discarded rather than repaired. Nonrepairable refers to a physical constraint; such constraint is often a matter of degree, e.g., a unit can be nonrepairable by the ordinary user but be repairable at the factory. A discardable unit need not be nonrepairable, i.e., it might well be repairable under some circumstances.

Examples are small dc power supplies and automotive alternators. Both are usually replaceable units. Each could be discardable and/or repairable (depending on circumstances) in both commercial and military practice.

2-2.2 NATURE OF DESIGN FOR DISCARD

The concept of discard must be viewed as broadly as possible. Basically, the concept is that an unsatisfactory item leaves the Army system with as few Army resources (people, time, and money) expended upon it as is feasible. For example,

1. Items that are traditionally discarded, such as ordinary burned-out light bulbs or blown fuses, are disposed of as trash with a negligible chance of discarding a good item. Little or no Army resources are consumed in training or in equipment for such discard. Items that must be disposed of carefully are usually given more attention.

2. An automotive generator (or alternator) that tests "not good" is to be discarded. A private contractor might wish to buy such items from the Army, rebuild them, and resell them to the Army as reconditioned items that will be "like new". Little or no Army resources are consumed in training or in equipment for such activity because what happens outside the Army does not consume any manpower, time, or money from the Army.

3. A printed circuit (PC) board is designated as a culprit in a nonfunctioning item of electronic equipment. The PC board consists of a socketed, expensive microprocessor and many soldered-in-place inexpensive components; that is, it has already been designed for discard because it is largely unrepairable. It is sent to a depot, which has test equipment with low risk of evaluating the PC board incorrectly. The PC board as a whole is judged to be bad and is discarded after removal of the expensive microprocessor from its socket. The microprocessor is now considered a separate discardable item. It is returned to stock if it tests good; otherwise, it is discarded.

The design for discard discipline requires that designers consider the total cost of an item, including the total cost of repair or disposal, over the life of the systems in which the item is used. A general goal is to reduce the total resources that the Army allocates to the maintenance function.

2-2.3 LIMITS OF DESIGN FOR DISCARD

The limitations surrounding the design for discard discipline are psychological barriers, cost barriers, current practices, and the need for flexibility caused by requirements that change. These limitations are discussed in the subparagraphs that follow.

2-2.3.1 Psychological Barriers

Few people want to throw away an item if its initial cost was high. Fewer people are interested in complicated, detailed analyses of the ultimate overall costs of repairing an item; they prefer to view the world in simpler terms such as the cost of repair parts and direct cost of repair time. Engineers and managers, as well as policy makers in the Army, the Department of Defense (DoD), and the Congress tend to remember the personal economic lessons of their youth rather than the hard economic facts of the present. Some politicians and some news reporters are more interested in inflammatory headlines about what is being thrown away than they are in rational analysis. Thus psychological barriers to design for discard must be broken down by all the people involved in the acquisition process as well as by the public at large. The Army has to allocate adequate resources for the necessary training, education, and testimony.

2-2.3.2 Cost Barriers

There are some inexpensive items that are already designed to be thrown away. Virtually no electronic item that costs less than $200 or an electromechanical hand tool or appliance that costs less than $100 is worth repairing or even repairable (except perhaps for removing the power cord) whether a civilian or military item. As the initial cost increases, a life cycle cost analysis, which includes not only the initial cost but also all the costs to repair and retain ownership, becomes more appropriate. In many Army situations it would be impractical to design an item for discard if the initial costs were high. The two main reasons for this are the psychological barriers and the concern about the validity of the design for discard analyses. There are a few inherently nonrepairable components that exceed the cost barrier, but those items were not intentionally designed for discard.

2-2.3.3 Current Practice

Many commercial and industrial products in highly competitive markets are already being designed for discard if it is economically feasible to do so. Examples are electronic products for the home and office, electromechanical hand tools and appliances, and automotive parts. Insofar as the Army is a small part of such markets, it cannot influence those practices very much.

2-2.3.4 Flexibility of Design

The traditional approach to system design in the 1960s and 1970s was the so-called "waterfall" procedure. That procedure insisted on a complete, rigid, formal system specification before the work began and then on contracting, delivery, installation, and maintenance. Almost any change was catastrophic in terms of both schedule and cost. That thinking is disappearing today because technology and threats are changing so rapidly that a project must be adaptable enough to change with them. Flexibility can be introduced into the acquisition process to the benefit of all. In design for discard it is possible that the Army will later change its mind because of changes, such as perceived threat, technology, cost of components, acquisition policy, political climate, environmental difficulties, and/or social objectives. For example,

1. A Jeep engine is designed to be discarded, except for minor repairs. Once the engine has been in service, the Army could change its mind and decide that for political reasons it is not feasible to discard an engine if it could be overhauled.

2. A printed circuit board is designed with sockets for the integrated circuits so that they can be replaced. Technology soon makes the total cost less to discard the board than to replace components on it. This example is similar to Example No. 3 in subpar. 2-2.2.

2-2.4 REALISM OF MODELS

Models* are essential for any engineering analysis, but they are always approximate, e.g., Hooke's law (stress is proportional to strain) and Ohm's law (voltage drop is proportional to current). The more complicated the situation being modeled, the more approximate the model. All that can be asked of model is that it be adequate for the purposes at hand and that its assumptions and limitations be clearly stated. As new technology is introduced and/or the requirements for the product or process become more strict, models that were adequate can become inadequate. Ref. 1 graphically demonstrates that difficulties with models have plagued engineers for centuries and millenia. Models that have been fit to historical data should be suspect because

1. Some of the nominally independent variables are often mutually dependent on a common cause. For example, a cautious designer might do two different things such as modularize a system and derate many of the components.

2. A sorting process separates two parts of a population so they should not be treated the same. For example, two plants make the same equipment. The items from Plant A are used in a cool, dry climate by skilled personnel, whereas the items from Plant B are used in a hot, humid climate by relatively unskilled personnel.

3. There are myriad statistically correlated variables, and it is virtually impossible to know what is cause and what is effect and how causes and effects are related. An example is prediction of the weather.

In developing a model, it is essential that all the assumptions be written down in a structured form so that developers and users alike can know exactly what problem is being modeled, how it is being modeled, the source of the numbers being used in the model, what kind of data the user needs to provide, and how sensitive the answers are to the accuracy of the data. The difficulties are exacerbated for complicated, computerized models and relatively unsophisticated users.

In design for discard the use of cost models is essential. Those models, of necessity, are approximate—especially those used very early in the acquisition process. The user must be told the appropriateness and accuracy of the model, its sensitivity to the quality of the input data, and how much engineering judgment to use in interpreting the results.

2-3 FORM, FIT, AND FUNCTION

Form, fit, and function refer to a method of design and production wherein the contents of a module are irrelevant as long as the performance of the module is virtually indistinguishable from that of the original module. Design for discard should be considered here as part of the overall design before incorporation of detailed specification requirements.

Form refers to the physical shape of the module, so that appearance, airflow, heat transfer, etc. will remain unchanged.

Fit refers to all the physical interconnections with the system. For example, all the bolt holes, electrical connectors, and mechanical bosses are unchanged.

Function refers to the internal performance characteristics and all the performance interfaces with the rest of the system. For a mechanical system the torques, moments of inertia, measures of flexibility, etc. must be the same. For an electrical system the input voltage-current characteristics (both steady state and transient), the output voltage-current characteristics, gain, frequency, noise, etc. must be the same.

A common problem arises when individual functions are enhanced. For example, the frequency characteristics of an amplifier or logic system can be improved. But such improvement can cause an old system to oscillate because the oscillation had been prevented by the poor frequency response of the module.

Interfaces are notoriously difficult to specify accurately and completely enough. This means that a module that was intended to have the same form, fit, and function might do well in some applications and do poorly in others. This can be especially true in design for discard wherein the construction methods of the module and its enclosure may be intentionally different from the item it is replacing.

Form, fit, and function might be easier to achieve under design for discard because many of the repair functions (except installation, testing, and removal) can be relaxed or eliminated altogether. The reliability function can often be improved because assembly techniques can trade off maintainability for reliability. For example, the sockets on a printed circuit board are often less reliable than direct soldering of the components.

2-4 COMMONALITY

Commonality is the term used when a module can be common to several systems. Traditional parts, such as resistors, power supplies, fuses, bolts, motors, and gearboxes, are examples of commonality. In order to improve commonality, the variety of a class of parts, such as bolts, is often restricted to specified sizes. Even though this restriction can result in some overdesign, the entire supply system is simplified enough to make it worthwhile.

Commonality of modules means that more of such items can be ordered and thus reduce their price. The potential to improve their specification, quality, and reliability exists because the total resources available for such activities can be devoted to fewer different modules. The cheaper and more reliable a module is, the more likely it can be discarded rather than repaired. The potential for more efficient repair facilities exists for the same reason.

*We never analyze the real world; we analyze only an abstraction of the world, by definition of "analyze". These abstractions are called conceptual models. If there is extensive mathematics in them, they are called mathematical models or, simply, models.

MIL-STD-965, *Parts Control Program*, (Ref. 2) is a required tool in any project to facilitate the control and restriction of parts. Other documents affecting this subject are MIL-HDBK-402, *Guidelines for the Implementation of the DoD Parts Control Program*, (Ref. 3) and Department of Defense Instruction (DoDI) 5000.2, *Defense Acquisition Management Policies and Procedures*, (Ref. 4).

2-5 MAINTENANCE LEVELS

The levels of maintenance considered in this handbook are unit (user), direct support (DS) and general support (GS) (field), and depot. The parenthetical names have also been used to describe the respective levels. AR 750-1 (Ref. 5) fully describes each of the four levels. Normally the first level of maintenance is at the unit, perhaps even by the operator. Often the highest level of support (depot) is by a contractor.

Two important factors for each maintenance level are

1. The hardware indenture level at which diagnosis and replacement are made
2. The skill, training, and repair facilities for the maintenance personnel.

Maintenance at the unit level especially must consider the amount of concealed damage that could be done by the maintenance person during diagnosis and repair or during checkouts and preventive maintenance if proper attention has not been paid to those two factors. That is a reason why unit level maintenance is authorized to deal only with reasonably rugged assemblies and parts.

For a discardable item at the unit level especially, testability is extremely important because the risk of discarding a good item and the risk of keeping an inadequate item should be small. The test criteria for each action (discard or send to a higher level) should be set to minimize some important resources. For example, for a given test technology for a very expensive part, the risk of discarding a good item could be made very small, whereas the risk of sending a good item to a higher level (for further checking) could be allowed to be rather high.

There are strong advantages to eliminating DS and GS levels of maintenance if it is physically feasible to do so. Higher hardware indenture levels of discard can help make such elimination more feasible.

Operational readiness, as a function of the levels at which maintenance is allocated, is directly affected by a design for discard program. The Army tries to optimize the allocation of maintenance by assigning each task to the most cost-effective level*.

Sustainability is more directly affected by the allocation of maintenance to each level, especially when more items are discardable. When the logistic burden is decreased at the unit, DS and GS levels, sustainability is likely to be appreciably improved unless the freed resources are virtually all allocated elsewhere. Sustainability is much more sensitive to the time duration of an activity, whereas readiness is much more of a steady state situation.

*Lower levels are preferred, other things being equal.

2-6 MAINTENANCE PROCEDURES

The two major types of maintenance are corrective (unscheduled) and preventive (scheduled). Both kinds can be done at any maintenance level. Preventive maintenance traditionally is done after a certain amount of exposure, such as time, distance or cycles. However, it is often much more efficient to measure the condition of an operating item and perform preventive maintenance only when the condition of the item requires it. The disadvantage is that the item must be characterized (all its elements, use, and expected results fully known and described) much more thoroughly so that testability can be improved. Even with this "reliability-centered" or "on condition" maintenance, it is still necessary to replace some items based on exposure rather than on their state.

Preventive maintenance can often be done profitably while a system is down for corrective maintenance. Appreciable increases in readiness can be obtained in this manner for complex mechanical systems wherein, for example, teardown time is a major fraction of downtime. Such benefits require that the procedures be planned well in advance and that simple decision methods be available. Designs that allow degradation to be self-announcing are especially useful. A simple example is caliper brakes on automobiles wherein the brakes squeal shortly before they need servicing.

Simple servicing, such as adjustments, fluid changes, and fluid level checking, are generally done only as preventive maintenance. More complex activities such as replacement and overhaul can be done on either occasion. Removed items can be discarded, salvaged, or sent to a higher level of maintenance. Often larger modules can be replaced at unit level maintenance, and the modules are then sent to DS, GS, or depot maintenance, where better facilities are available, for more detailed repair. This action is necessary because the ability to test and repair is less at unit level maintenance. Items that are fully testable and discardable at unit level maintenance can reduce the transportation burden.

The maintenance concept provides the framework for

1. Allocating maintenance resources to the maintenance levels
2. Providing logistic design requirements for the product being developed.

During the engineering and manufacturing development phase, a level of repair analysis (LORA) must be performed again for detailed optimization of allocation of repair activity to each maintenance level. The constraints on the maintenance concept for mechanical systems are generally different from those for electronic systems. For mechanical systems the diagnosis time is generally small compared to the active repair time, whereas the situation is generally reversed for electronic systems.

The general goal of the design for discard discipline is to reduce the overall maintenance burden. Special consideration must be given to the unit level, at which the function is usually accomplishment of a combat or combat support mission, not a maintenance mission.

2-7 DESIGN TECHNIQUES

Generally, reliability and maintainability are traded off against each other. Many of the techniques used to improve one are detrimental to the other. Damage could be caused by preventive maintenance. For example, an inspection cover could be left off or an improper adjustment could be made. An instrument could give a false reading, which is how the Three-Mile Island nuclear plant shutdown was caused. Testing has its dangers. The Chernobyl meltdown was caused by a routine simulation that escalated into the very catastrophe it was designed to prevent.

On a detailed level, permanent fastening is virtually always appreciably more reliable than removable fastening. For example, soldering or wire-wrap is more reliable than sockets and connectors, and riveting, brazing, or welding can be more reliable than threaded connectors. Conformal coatings and foam-in-place filling of voids improve reliability at the expense of maintainability. Many of the techniques that reduce maintainability are cheaper.

To take advantage of such tradeoffs, the products and processes to make them must be well characterized. (See Glossary for definition of characterize.) The more complex the situation becomes, the more important it is for the design and production* engineers to have structured, convenient knowledge available. Computer-aided design (CAD), computer-aided engineering (CAE), and computer-aided manufacturing (CAM) are contemporary methods to help the design and production engineers implement such knowledge concurrently. Concurrent engineering is a method to break down the walls that so often separate the engineering disciplines. Appropriate computer programs can present the designer with alternatives for design for discard that the designer might otherwise neglect. More important than the tools, however, is the mind set of the designer. Traditionally, repairability has been a most important design characteristic; the stigma must be removed from nonrepairable items.

2-8 ANALYSIS AND DECISION TECHNIQUES

Several kinds of analysis and decision techniques are available to the designer. An introduction to these techniques follows:

1. *Cost Elements*. The direct cost elements, such as the purchase price of an item, purchase price of test equipment, and salaries of maintenance technicians are important but not a difficulty in the analysis. It is much more difficult to find and use indirect costs, such as the total cost of training the technicians, cost to enter and maintain items in the supply system, storage costs, requisition costs, and total costs of transportation of items between maintenance levels. See par. 10-2, "Cost Elements", for more information on this topic.

2. *Design Analysis and Tradeoffs*. There are several kinds of models for design analysis and tradeoffs. Some of them are

a. Straightforward design analyses in which the parameters of a module are calculated from the design. These analyses are needed regardless of the level of discard.

b. Cost-performance models for various designs. Performance should include reliability.

c. Direct repair costs as a function of the maintenance level

d. Indirect repair costs as a function of the number of technicians and their skill levels.

The problems encountered in using some of these techniques, especially the last two involving repair costs, are compounded by the short-term vs long-term considerations. See par. 10-4, "Tradeoff Analyses", for more information on this topic.

3. *Level of Repair Analysis*. From a mathematical model these procedures predict the optimum maintenance level at which a particular hardware indenture level of repair or discard should take place. Such analyses should include sensitivity calculations that show how narrow the optimum point is with respect to variations in the numerical parameters of the model and, where feasible, with respect to some of the assumptions in the model. These analyses generally require the use of approved computer programs. See par. 10-5, "Level of Repair Analysis (LORA)", for more information on this topic. AMC-R 700-27 (Ref. 6) identifies the approved techniques used to conduct LORA; AMC-P 700-4 (Ref. 7) provides some basic information on all approved techniques. MIL-STD-1388-1A (Ref. 8), Task Section 300, should be used for the preparation and evaluation of alternatives. Subtask 303.2.7 could be used to form economic estimates to determine design for repair or design for discard early in the life cycle.

4. *Front-End Analysis*. Essentially, this is any analysis that is done in the early acquisition phases. Specifically in this handbook it is any early analysis that relates cost to the design and the maintenance concept. Life cycle costs, personnel (numbers and skill levels) requirements, and repair vs discard decisions are the important front-end analyses. See par. 10-3, "Front-End Analysis", for more information on this topic.

5. *Military Requirements*. These address both the specific project requirements and the combat developer's long-

*The terms "manufacturing" and "production" are considered to imply the same things in this handbook. Some companies do distinguish between the two terms, especially as applied to engineers, but that distinction is not the same among companies.

range goals for readiness, sustainability, and logistic support. In some cases tradeoffs must be made between the long-term goals and the specific project requirements, as far as the design for discard program is concerned. Such tradeoffs should be guided by the explicit relative importance the combat developer assigns to those aspects of the situation. See par. 10-6, "Long-Term Military Goals", for more information on this topic.

2-9 SYSTEM-ENGINEERING INTERFACES

In any project there is a variety of programs and related system requirements imposed upon the design group. The optimum design is a "balancing act", which creates a common interface among all of them. An introduction to some of these interfaces follows:

1. *Reliability Engineering*. This is the set of design, development, and manufacturing tasks by which reliability (the user's ability to depend on something) is achieved. In general, the demands of design for discard and reliability are similar in that improved reliability at a reasonable cost makes it easier to discard an item upon its failure. See par. 11-2, "Reliability Engineering", for more information on this topic.

2. *Reliability-Centered Maintenance*. Reliability-centered maintenance refers to preventive maintenance that is performed when the condition of the item, related to its projected reliability, requires it. For further discussion see par. 2-6, "Maintenance Procedures". In general, the demands of design for discard and reliability-centered maintenance are similar in that longer periods between maintenance actions decrease the ownership cost of an item. Such maintenance requires that the item be characterized more completely than is needed for simple measures of use, such as time, miles, or cycles, and that the testability of the item be sufficient to allow the state of the item to be evaluated adequately. These requirements can increase the engineering and manufacturing development phase cost and the unit production cost. See par. 11-3, "Reliability-Centered Maintenance", for more information on this topic.

3. *Maintainability Engineering*. Maintainability refers to the concept of being able to support an item within constraints such as downtime, skill levels, and tools. Maintainability engineering is important in two ways:

a. The item must be removable and replaceable, as always.

b. The item must be testable to a greater degree than usual to mitigate the risk of wrong decisions for discard.

Thus the challenges to maintainability engineering are similar to those for reliability-centered maintenance. See par. 5-3, "Technologies of Testing", for more information on this topic.

4. *Producibility*. Generally, the challenge to producibility (the ability to provide an item in an economic and timely manner) is in being familiar with various materials, testing, and assembly techniques different from those ordinarily used. Once that problem is recognized and assimilated, producibility can be improved for an item that is designed for discard, as compared to a conventional repairable item. For example, soldered electrical connections on a PC board are cheaper to produce than sockets and plug-in parts. See par. 8-3, "Fabrication Techniques", for more information on this topic.

5. *Manpower and Personnel Integration* (MANPRINT). It is the intent of design for discard to have a strong effect on the number and skill levels of maintenance personnel. Some items may have to be designed for discard simply because manpower limitations do not allow for repair. Built-in test equipment (BITE) must be designed for easy access and operation. Initiation of built-in testing must be simple, and the results must be easy to interpret. Form and fit play an important human factors engineering role because discardable parts must be designed for easy removal. See Chapter 12, "Interface With MANPRINT", for more information on this topic.

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6. AMC-R 700-27, *Level of Repair Analysis (LORA) Program*, 20 February 1991.
7. AMC-P 700-4, *Logistic Support Analysis Techniques Guide*, 20 February 1991.
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CHAPTER 3
ADVANTAGES AND CONSTRAINTS

The advantages of designing for discard are explained. The potential advantages include better producibility, less documentation and manpower, lower skill levels in maintenance activities, and reduced need for transportation of supplies. Areas such as operational availability, mobility, packaging, handling, storage, and support equipment are treated in terms of the tradeoffs that must be made during design. Finally, the implications and constraints implied by peacetime vs wartime and by short-term vs long-term considerations are discussed.

3-1 INTRODUCTION

Generally, an item designed to be discarded must meet the same performance specifications as a similar item designed to be repairable, but design of the discardable item can take advantage of less costly fabrication techniques. For a fixed number of items that are ready for use or are in use, an additional number must be purchased because of the burden of filling the supply pipeline. Trained people are needed to operate such pipelines and the associated acquisition and maintenance activities. A large overhead in terms of people and facilities is needed to generate those trained people.

Many of the activities associated with constraints are institutionalized in the Army and thus are traditionally considered sunk or fixed costs. An aggressive design for discard program requires that such institutions be challenged and incorporated into the design for discard cost/benefit models. The purpose of this chapter is to illuminate these tradeoffs and treat some of the constraints in solving them.

There are several qualities or capabilities of the fighting forces that the Army might wish to keep relatively constant, regardless of any changes in its acquisition process. Examples of such qualities or capabilities included in this chapter are the characteristics of operational readiness and mobility. Although acquisition changes, such as a design for discard program, might free some resources, the Army could reallocate those resources for other purposes or dispense with them altogether. Such decisions are influenced by the President, Congress, and the Department of Defense.

3-2 LIFE CYCLE COSTS

Life cycle cost, viz, the total cost of ownership, can be reduced by raising the hardware indenture level for discard. Two difficulties in analyses for improvements in life cycle cost are

1. Having a baseline life cycle cost as a reference for comparison
2. Being able to quantify all the components of the life cycle cost that are important in the problem at hand.

Considering design for discard in a design has no direct effect on the first difficulty (a baseline) because with or without a design for discard, a baseline must be chosen so that the various alternatives can be compared. The second difficulty, however, does arise and was a major reason for the push toward design for discard. There was the belief that the Army could profitably challenge some of its historically fixed costs, viz, the total cost of training for maintenance.

Since the mid-1980s, however, there has been a growing concern about how this country handles its discarded items, and that concern shows no signs of abating. Thus the cost of physically disposing of even relatively benign items will continue to rise; the cost of disposing of all nonbenign items will soar. In principle, cheaper, less reliable items might result from a design for discard analysis, but it is quite likely that the surest way to reduce life cycle costs is to make equipment much more reliable—even reliable enough so that equipment failure rates are less than 0.1% per month which is a nominal mean time-to-failure of over 80 years.

As the level of discard moves toward larger assemblies—higher hardware indenture level—the Army can reduce its cost of ownership of equipment by eliminating or reducing the repair costs and their associated overhead. These reductions can occur because of fewer highly skilled support people, less test and repair equipment, fewer facilities, and higher reliability of the items. Virtually all other factors are generally either negligible or tend to increase the cost. A very long-term benefit is to reduce the cost of spares inventories. The short-term costs of such inventories, however, are almost certain to rise.

The following paragraphs discuss the cost problems in more detail: 3-3, "Producibility"; 3-4, "Manpower and Skills"; 3-6, "Transportation Requirements"; 3-8, "Packaging, Handling, and Storage"; 3-9, "Support Equipment"; and 10-2, "Cost Elements".

3-3 PRODUCIBILITY

Generally, an item that is completely discardable is potentially cheaper and easier to produce over the long term than a comparable item that is repairable. In commercial practice one of the big incentives for design for discard is the reduction of product complexity to achieve better producibility. When only portions of an item are discardable, there can be some tradeoffs, but even then an item is probably more producible than if it were completely repairable.

In the short term, however, a particular company might incur some producibility difficulties due to a radically different design. The design of a discardable item can require different production equipment, raw materials, and personnel skills than are available, e.g., plastic molding presses instead of metal machining. Many companies still generate their profits by producing things rather than by hiring subcontractors. Thus better producibility as a result of design for discard might require considerable capital investment to keep the entire process in-house, and longer initial production lead time would follow.

3-4 MANPOWER AND SKILLS

The effects of design for discard on manpower and skills are different at each level of maintenance. The effects are

1. *Unit Level Maintenance.* Insofar as maintenance is a test-and-replace operation and insofar as system reliability is not worsened, there is negligible difference in the manpower needed for discardable vs repairable items. For items that require complex or expensive test equipment, the usual procedure is to forward the item to the next higher level of maintenance for testing and disposition.

2. *Direct Support (DS) and General Support (GS).* The need for test skills will remain about the same as for repairable items in both direct and general support functions. The need for repair skills will be nil for completely discardable items. For items that contain salvageable removable modules, some repair technicians will be needed, but their numbers and skill levels will be appreciably lower than for the usual repairable items. Since one person is normally both the test and repair technician, the balance of skills that technician needs might well change.

3. *Depot Level Maintenance.* If discardability is used, the need for test and repair technicians will be appreciably less—both in numbers and skill levels—than for repairable items because many fewer items will even reach the depot level, except for salvage and/or disposal. However, in the transition from maintenance by repair to maintenance by replacement, more supply personnel might be required at higher echelons.

3-5 OPERATIONAL READINESS

Operational readiness is "The capability of a unit/formation, ship, weapon system, or equipment to perform the missions or functions for which it is organized or designed." (Ref. 1).

Operational readiness could be improved by the effect of design for discard on the tooth-to-tail ratio. It would be affected largely by the degree to which design for discard reduces dependence on skilled technicians. The amount of Army resources devoted to achieving a given state of operational readiness should be less with such a program, and the mix of people and equipment would be different. That is, the Army requires a certain operational readiness for each of its elements and will expend the amount and mix of resources necessary to achieve it.

3-6 TRANSPORTATION REQUIREMENTS

Transportation costs could be reduced if a design for discard item is disposable at the unit level provided that one-way transportation is considered a savings, but it is unlikely that overall requirements would be reduced appreciably by a design for discard program. Transportation between unit level maintenance and DS or GS level maintenance would stay about the same because complete items would go toward the unit level rather than some repaired elements. A similar situation exists for transportation between DS or GS level maintenance and depot maintenance, i.e., larger items would be going toward the DS or GS level whether from a depot or some other source of supply.

If a discardable item is more reliable and its other characteristics (weight, volume, etc.) are no worse, the amount of transportation devoted to such an item can be reduced because it would need transport less often. An example of other characteristics being worse is improving reliability of a nonrepairable unit by using redundancy such that the unit fails if and only if all of its redundant elements fail. Such redundancy could double the weight and volume of the unit and actually increase transportation needs.

3-7 MOBILITY

Mobility is "A quality or capability of military forces which permits them to move from place to place while retaining the ability to fulfill their primary mission." (Ref. 1). With increased reliability as a result of design for discard, some spares or replacement parts would not have to be stocked at unit level and would thereby increase mobility. There would still be a need for repair and/or replacement parts, regardless of the hardware indenture level at which test and replace occur. Mobility is an operational characteristic, and what actually happens depends on what the Army tries to hold constant, e.g., it could keep the same mobility by reallocating resources.

3-8 PACKAGING, HANDLING, AND STORAGE

Minor impacts on packaging, handling, and storage are foreseen as a result of a design for discard program; these things depend much more, for example, on equipment reliability. A radio with a failure rate of 0.1% per month would require very few spares and little packaging, handling, or storage. Another example is that a discardable item could be sealed better than the corresponding repairable item, and thus it would be less susceptible to its storage environment. Better sealing not only keeps the external environment out, it also retains the internal environment.

3-9 SUPPORT EQUIPMENT

There may well be opportunities to reduce the amount and complexity of support (test and repair) equipment in general. It is convenient to classify support equipment as system peculiar or common purpose, as follows:

1. System peculiar support equipment, by its nature, can be used on at most a very few items. Generally, it is designed and produced explicitly for the equipment on which it will be used. If the test equipment is separate from the unit under test, the training and skills needed to use it can be more than for common-purpose support equipment. On the other hand, if the test and/or test equipment is built in, the opposite is true. Because of low production runs, system-peculiar support equipment can easily be more expensive and less reliable than common support equipment. Insofar as discardable items may require more special external equipment, the cost may be higher and may make the discardable item less desirable.

2. Common support equipment, by its nature, can be used on many items. It is often used in the commercial as well as the military world and can be purchased as a nondevelopmental item.

It is convenient to classify support equipment as functional (Go/NoGo) or parametric as follows:

1. Functional test determines merely whether an equipment conforms to appropriate specifications or not. It does not diagnose the cause of a nonconformance. Such equipment is generally less expensive and more standard than parametric test equipment and is more likely to be suitable for discardable items.

2. Parametric test equipment is used to diagnose what needs repair on a repairable item (fault isolation) and may also be used to perform that repair. This is likely to be required for repairable units because fault isolation is necessary to some lower level.

Discardable items require only functional test equipment, not diagnostic and repair equipment, even if some subitems are removable. Thus discardable items will eventually require much less diagnostic and repair equipment.

3-10 DOCUMENTATION

The two kinds of important documentation related to design for discard are

1. Technical manuals that address test and repair
2. Documentation required in the Government supply system.

The technical manuals for discardable items would contain only the instructions on how to conduct appropriate functional tests. Repair instructions are not needed; thus they need not be written nor printed. Remove and replace instructions are still needed, however. The documentation for the Government supply system will initially increase because a new item has been added to the supply system. This increase, however, will be smaller than if the item had been repairable, and in the long term such documentation might decrease.

Although it is certainly true that some documentation is required to measure and control contractor performance of design for discard adequately, a concerted effort should be made to hold such documentation to the minimum. Data item documentation is not needed to accomplish this goal.

3-11 PEACETIME vs WARTIME

It is easy to lose sight of the fundamental mission of Army materiel: Support the Soldier in the Field! When dealing with mathematical cost-effectiveness models and with justifications in the presence of budget constraints, it is easy to forget the differences between peacetime and wartime in terms of emphasis on Army objectives. In peacetime an important objective is often to minimize operating and support costs. In wartime operational readiness, mission reliability, and system effectiveness are among the primary objectives in supporting the soldier in the field. Operating and support costs and some measures of readiness used in peacetime are secondary considerations.

All Army training and procedures are for wartime because it is impossible to train soldiers differently for peacetime and wartime. The Army design for discard program operates the same in peacetime and wartime, even though what happens to items outside of the Army system might well be different in the two situations.

3-12 SHORT TERM vs LONG TERM

Some problems are made worse in the short term because the repairable and discardable items exist together. Examples are

1. More training is needed so that both operating and repair personnel know how to tell which version of an item is repairable and which is discardable.

2. The logistic support system has another item (the discardable one) to deal with in addition to all the existing ones. If the repairable version used repair parts with high commonality, those repair parts stay in the system, regardless of the discardability of the new version.

3. Even though fewer repair people might be needed, the personnel system may react slowly to the changing needs, and the repair crews may temporarily remain at the same size. In some situations the minimum size of crew is set by other considerations, such as safety.

Improving the "tooth-to-tail" ratio (fighting capability to support capability) may involve additional expenditures over a long period of time. It is difficult to maintain enthusiasm and vigor in any program once the initial push is over and the initial proponents have gone on to other things. Commitment of up-front resources that are to be recovered in the long term is not in vogue, and the design for discard program does not escape this pressure.

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CHAPTER 4
TECHNOLOGY SURVEILLANCE

Three sources of future technology and the Army program for sponsoring, reviewing, and using the technology are briefly explained. Sources of information about new technology are discussed.

4-1 INTRODUCTION

The Army is vitally interested in developing and using technology for all of its programs and projects not only for a design for discard program. The three sources of future technology are Government research, industry research, and academic (university) research. Foreign research is also monitored and used by the Army but is not explicitly included in this handbook. This discussion is purposely general, and most of the material in pars. 4-2, 4-3, and 4-4 is adapted from Ref. 1.

A major way that any research, regardless of who sponsors it, moves from the laboratories to the engineering professions is by the traditional routes of trade publications and conferences. Lesser but nevertheless important routes are professional symposia and journals. An engineering command or project office should be staffed principally with engineers who are technically competent and who continue to work in their fields.

Appendix A lists some of the engineering trade magazines. Reading these magazines is one of the best ways to stay current with technology and research.

4-2 GOVERNMENT RESEARCH

The Army implements its research programs through the Army Research Laboratory (ARL) and its research, development and engineering centers (RDECs). The Army Research Laboratory is generally concerned with generic basic and applied research, whereas the Army RDECs are primarily responsible for commodity-oriented research. The ARL and the RDECs

1. Analyze baselines and assess the feasibility of technology performance envelopes
2. Review threat issues to ensure that planned requirements and evolving technologies address the anticipated threats
3. Ensure the flow of information within the Army test and evaluation community about the testing requirements of new technology, ensure the timely development of test technology, and ascertain the availability of test resources.

The movement of technology from the ARL and RDECs to design and development is straightforward because the people most concerned with any particular technology are sponsoring and/or monitoring it.

"The Defense Technical Information Center (DTIC) is the central point within the Department of Defense (DoD) for acquiring, storing, retrieving, and disseminating scientific and technological information (STI) to support the management and conduct of DoD research, development, engineering and studies programs." (Ref. 2). The specifics of information retrieval are in a registration package, which can be obtained from

Defense Technical Information Center
Building 5, Cameron Station
Alexandria, VA 22302-6145.

Additional information is contained in, PB91-180216, *A Directory of Scientific and Technical Information Programs in the US Government* (Ref. 3), and PR-827, *1992 Catalog of Products and Services,* National Technical Information Service (Ref. 4). These publications are available from

National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161-0001.

According to both DTIC and the National Technical Information Service (NTIS), there is no clearinghouse for locating all research still in progress because only results are reported.

The Electronics and Electrical Laboratory (EEEL) of the National Institute of Standards and Technology (NIST) publishes (quarterly) the *EEEL NIST Technical Progress Bulletin* (Ref. 5). It contains abstracts of papers about the work of the NIST on electrical measurements, semiconductors, signal acquisition and processing, electrical systems, and electromagnetic compatibility. It is available from

EEEL Technical Progress Bulletin
Metrology Building, Room B-358
NIST
Gaithersburg, MD 20899.

4-3 ACADEMIC RESEARCH

Academic research is a combination of basic research (without a particular application in mind) and applied research toward specific goals. Virtually all such research is supported by grants from industry, foundations, and Government. Most such research is done by colleges and universities; some is done by industry consortia, such as the Semiconductor Research Corporation in North Carolina. There is no publication that lists academic research in progress. Virtually all such research is reported in technical journals and in technical reports published and distributed by the research group involved. Basic research generally passes through an applied research program before it becomes useful to a design for discard program.

The Army funds academic research through the US Army Research Office (ARO) with the assistance of the National Research Council, the ARL, and RDECs. There are two main types of programs:

1. A single principal investigator who is assisted by graduate students and some faculty members
2. Centers of excellence that acquire state-of-the-art instrumentation and have a team that conducts advanced research in the designated field for projected military applications.

The ARO program is described in *Broad Agency Announcement* (Ref. 6).

4-4 INDUSTRY RESEARCH

Industry research is classified as

1. Development of materials and processes by those who sell them to others. This technology is available to the Army for its development work.
2. Development of products for sale, e.g., components, operating modules, or systems. These products, rather than the technologies to create them, are available to the Army as equipment or modules.

The Army has two ways to support and guide such research:

1. Contract research and development for which the Army supplies about 70% of the funding. This work is generally done by companies in the business of providing Army materiel.
2. Independent research and development projects that are initiated and run by industry but are reviewed by DoD laboratories and RDECs. Industry can recover some of its costs according to formulas negotiated in accordance with the appropriate Federal and DoD Regulations. The amount of cost recovered by industry is approximately 30 to 40%. The DoD receives information from industry about this research in return for those funds and for information about DoD plans and needs. The US Army Materiel Command (AMC) manages the Army participation in this program.

Insofar as industry research is solely for its own use, it gives only as much priority for design for discard as good business dictates, whether civilian or military. As mentioned previously, most electrical hand tools costing under $50 and electronic items costing under $100 are not economically repairable.

Insofar as industry is responding to a perceived or stated military need, it is presumably quite willing to apply materials and processes, new or old, to design and develop discardable items. Industry, however, is likely to want some assurance that the need for such development will not change without a valid reason. That assurance can take the form of a contract to develop and/or produce such items or of the Army's having demonstrated its interest in design for discard.

4-5 USING CURRENT TECHNOLOGY vs PUSHING THE STATE OF THE ART

When technology can change appreciably during the acquisition process, the question should arise, "What technology should we use in the design and development process?"

At one extreme, especially where high reliability is essential, only technology that exists at the beginning of the design process is used. This procedure involves a negligible technology risk but can result in an item that is technologically obsolete before it goes into full-scale production.

In the middle there is preplanned product improvement (P3I) in which the product is designed with the flexibility to be improved as technology changes and/or needs are revised. This concept is in accord with the currently prevailing quality thrust of continuous improvement.

At the other extreme, the end-item is not even feasible or possible unless newer technology becomes available. For example, a smaller, more powerful computer might be needed, or a composite material with the requisite strength-to-weight ratio might be necessary. This approach involves appreciable risks of all kinds: technology, schedule, and cost. It can, however, result in an item that is superior to all others of its kind or even in an item that would otherwise be impossible.

Balancing all the risks is difficult and is subject to second-guessing by others. Mathematical models, preplanned product improvement, and technology insertion can be used to traverse these two extremes.

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3. PB91-180216, *A Directory of Scientific and Technical Information Programs in the US Government*, National Technical Information Service, Springfield, VA, April 1991.
4. PR-827, *1992 Catalog of Products and Services*, National Technical Information Service, Springfield, VA, October 1991.
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PART TWO
DESIGN CONSIDERATIONS

Part Two is the main part of this handbook and discusses four major areas that can strongly affect the discardability of an item and that are under control of the design and production* engineers. These areas are diagnostics, physical arrangement of components, choice of materials, and manufacturing methods and techniques. Although the engineering considerations are paramount, they must mesh with other system considerations, such as those presented in Part Three. Part Four summarizes some of the more pertinent program considerations for design for discard.

CHAPTER 5
DIAGNOSTICS

Diagnostics are briefly covered by explaining testability as it relates to various kinds of equipment, the simplified techniques that are used in testing, and the nature of functional testing. The relative importance of grouping items according to their function is also briefly discussed. Hypothetical examples are given to illustrate the ideas.

5-1 INTRODUCTION

The word diagnostics is intended to be general and to cover the process of knowing that something is wrong, deciding that the difficulty is worth fixing, narrowing the trouble to a replaceable unit, and after replacing the offending units, assuring that the equipment is working satisfactorily. "Diagnosis" has been defined more narrowly, e.g., in Ref. 1 it is defined as "The functions performed and the techniques used in determining and isolating the cause of malfunctions.".

Because testing is not useful unless the test measurements can be converted into a decision, the item and the tests must be well characterized. The concept of characterization is explained in subpar. 5-1.1.

Testing is not perfect; therefore, risks are associated with decisions that are based on test results. These risks and some of the nomenclature related to them are explained in subpar. 5-1.2.

The properties to be tested for depend on the kinds of failure of the item, especially if reliable operation is to be assured. Some simple models for failure are explained in subpar. 5-1.3.

Before testing is considered at all, the engineers' knowledge about potential malfunctions, faults, and failures should be organized in a way that is useful for planning diagnosis and executing corrective action. Several ways to organize such knowledge are explained in subpar. 5-1.4.

5-1.1 CHARACTERIZATION

The concept of characterization is at the heart of testing. In most testing the information really wanted cannot be readily obtained, e.g., the reliability of a crankshaft can only be inferred from some indirect measurements and the adequacy of a microcircuit is inferred from measuring only a small fraction of the possible excitations and responses. A situation can be defined as "characterized" if all the important properties and interactive relationships about it are known. The "situation" can be an item, process, environment, test, etc. For example, during test and repair, a repairable unit is characterized if exactly what to test for, how to test it, how to interpret the results, what to fix, and how to fix it are known.

Nothing can ever be completely characterized for all situations because scientific and engineering knowledge are never complete. Interfaces between items are usually incompletely characterized because not enough resources have been devoted to the problem and/or the intended application for the item under development has changed.

An item and its test are well-characterized for diagnosis if the following things are known and feasible:

1. What to measure (on the item and its elements)
2. How, when, and where to measure
3. How to convert those measurements into knowledge about the important characteristics of the item
4. How to combine that knowledge with knowledge of how the item will be used on the mission and how the item can fail
5. How to decide what to do with the item, e.g., run more tests or discard the item.

5-1.2 TESTS AND RISKS

Tests involve the risks of making an inadequate decision. A general vocabulary has been developed to describe some test results and test risks. It is presumed that an item is either good or not good (bad) and that "good" has been adequately defined in terms of all the requirements. Some terms of this vocabulary are

*The terms "manufacturing" and "production" imply the same things in this handbook. Some companies do distinguish between the two terms, especially as applied to engineers, but that distinction is not the same among companies.

1. *Test Good.* The test result is interpreted as "The item is good.".

2. *Test Bad.* The test result is interpreted as "The item is bad.".

3. *False Good.* The item tests good but is in fact bad.

4. *False Bad.* The item tests bad but is in fact good.

Some reasons for false results are

1. The test instrumentation was faulty, or the test results were interpreted incorrectly.

2. The test measures a secondary property of the item, not the property of real interest. The correspondence between the secondary property and the one of real interest is rarely exact.

3. The property being measured and/or the measurements themselves have uncharacterized fluctuations.

The criteria for test good can be often be adjusted so that the error probability can be moved toward the less dangerous or less costly of false bad or false good. For example, for an inexpensive test the probability of a false good can be made very low, with a consequent increase in the probability of a false bad. If the item tests bad, it is subjected to a more expensive, more accurate test for which the probability of either a false bad or a false good result is very small.

For a given amount of available project resources, the mathematical probabilities of false good and false bad do depend on each other. For those given resources, if one of the probabilities is improved, the other is worsened. If both must be improved, the project resources must be increased. For example, for hand grenades, if the probability of a premature detonation must be made smaller, the probability of a dud will become higher.

These concepts are related to statistical Type I and Type II errors and to the concept of producer (alpha) and consumer (beta) risks in acceptance sampling.

At each maintenance level the magnitude of testing errors is adjusted to fit the needs of the Army. For example, at the unit level of maintenance the probability of a false good should be quite low (with a resulting higher probability of a false bad) because the soldier in the field must be able to rely on his equipment. That is, the soldier in the field must not be attempting to use equipment or weapons that test good but are really bad; the results could be deadly. At higher maintenance levels the false good can be someone else's problem without the danger of loss of life. False bad results at the unit level can be decreased (while the same low false good level is maintained) only with better test equipment.

5-1.3 SIMPLE MODELS FOR FAILURE

It is important to understand what type of failure is being tested for because the failure type can restrict the kinds of tests that are effective and affect the kind of corrective action if a failure is discovered. The four simple models for failure that follow cover, singly or in combinations, most kinds of failure that are related to mission reliability of discardable items:

1. *Simple Stress-Strength.* The item fails if and only if the stress exceeds the strength. If the stress does not exceed the strength, the stress has no permanent effect whatsoever. This failure model depends on the occurrence of critical events in the environment rather than on the mere passage of time or cycles. The maximum allowable stress is placed below the strength so that the probability of failure is suitably low. A proof test is often performed for this failure model. In a proof test the test stress in the item is the rated strength, does not cause cumulative damage, and is well above the stress anticipated during any mission. If the item does not fail, it has adequate strength.

2. *Simple Damage-Endurance.* A stress causes damage that accumulates irreversibly. The item fails when and only when the damage exceeds the endurance. The cumulative damage does not degrade performance, so the amount of cumulative damage cannot be ascertained by measuring performance. An indirect measurement is often necessary.

3. *Simple Tolerance-Requirement.* A system performance characteristic is satisfactory if and only if its tolerance remains within the requirement. Under combat conditions there is often room for judgment on how much variation can be tolerated since the circumstances could make replacement or repair impossible.

4. *Simple Challenge-Response.* An element of the system is bad, but only when the element is challenged does it fail to respond, reveal itself as bad, and cause the system to fail. This failure model depends on when critical events happen in the environment rather than on the mere passage of time or cycles. Software failures are always of this type.

5-1.4 ORGANIZATION OF KNOWLEDGE ABOUT POTENTIAL FAILURES

In order to test intelligently and to determine the potential effect upon discardability in the design, knowledge about potential failures must be developed and then organized in a useful way. Three such methods are summarized here. More information about them is readily obtained in books on reliability engineering.

1. *Failure Mode, Effects, and Criticality Analysis (FMECA).* FMECA is among the oldest formal techniques in the United States used to organize knowledge about potential failures and is probably the most commonly used. It deals only with 1-point failures (A 1-point failure is an element failure that can cause the assembly to fail.) and thus cannot handle the effects of redundancy well. It is usually called a bottom-up analysis. Its major use is when knowledge of the effects is low and the effects can be devastating. Ref. 2 is devoted to this method.

2. *Failure Mode and Mechanisms Analysis.* This is an old technique without an established acronym. In many situations the effect and criticality of a failure mode are readily

known—the equipment fails and must be repaired. This is as true of electronic equipment as it is of mechanical equipment. Thus the FMECA is of no value in those situations. One begins at the failure mode and works backward to find the failure mechanisms of the failure mode, then to find causes of those failure mechanisms, and so on until there is enough knowledge for corrective action or adequate testing.

3. *Fault Tree Synthesis and Analysis*. This is a more complicated and difficult organizational technique; it is essentially a mathematical logic equation in picture form. It is often used in analyses related to safety and can handle multipoint failures. It is usually called a top-down analysis. Event trees and cause-consequence charts are related to fault trees but have other properties as well.

5-2 TESTABILITY

Testability is "A design characteristic which allows the status (operable, inoperable, or degraded) of an item to be determined and the isolation of faults within the item to be performed in a timely manner." (Ref. 3). An additional concept for testability is that conformance to all specifications should be determined in addition to operability. It is not uncommon for an item to test good and yet not function properly under the conditions for which it is designed. The reason for this is that the test does not cover the entire envelope of environmental, supply, and loading conditions.

Not only must an item function properly to be classified as good, but it must also have the mission reliability required for a new item. In order to test nondestructively for mission reliability, the item must be well-characterized. The important aspects of testability are divided into four categories: mechanical; electronics, electrical, and electromechanical; hydraulics and pneumatics; and optical and electro-optical. For simplicity and continuity in the discussions that follow, each category is organized according to the four simple models for failure presented in subpar. 5-1.3.

The designers will have organized their knowledge about potential failures in a useful way, such as those mentioned in subpar. 5-1.4. Precautions must be taken during design and development of both the item and the tests so that testing does no harm to the item or its neighbors. Such harm can occur inadvertently by the tester or as a consequence of the test stimulation.

5-2.1 MECHANICAL

Many mechanical items, especially those that carry loads, fail in obvious ways, so testing in the usual sense is not necessary. Examples are a broken motor housing and a severely warped gun tube. Such failures are not considered further. The mechanical portions of electromechanical items are by their nature included in this category. The discussion that follows is organized according to the four simple models for failure presented in subpar. 5-1.3.

1. *Simple Stress-Strength*. For load-carrying and/or load-transmitting mechanical items, simple stress-strength is generally not important. Its main application is in pressure vessels, e.g., hydraulic or pneumatic. A proof test is generally used to see whether the strength of the item is sufficient. Failure of an item during a proof test must be a safety consideration.

2. *Simple Damage-Endurance*. Indirect evidence of the damage is generally required because by definition the item will still pass a functional test. For example, cumulative fatigue damage can cause surface cracks; these cracks can be detected by liquid penetrant processes, such as Magnaflux™. Interior cracking or discontinuities can be detected by ultrasonics. The many kinds of cumulative damage for metals are generally well-categorized by metallurgists. Newer load-carrying materials, such as plastics, ductile ceramics, and composites, are not as well-characterized as metals; therefore, damage in such newer materials can be difficult to detect.

3. *Simple Tolerance-Requirement*. Wear, deformation, and corrosion are common examples of this failure model. Wear can be detected on the exterior by simple measurement, whereas wear on internal surfaces or internal damage is often detected by the vibrational signature of the item. An example is the readily discernible noise and subaudio vibrations from roller bearings that are wearing out. In principle, testing for deformation is straightforward; in practice, however, the allowable deformation can be so small that it is difficult to measure accurately enough. Excessive corrosion can often be detected by measuring the thickness of the remaining material or of the corrosive layer or the electrical characteristics of the corrosive layer.

4. *Simple Challenge-Response*. In mechanical systems this failure model usually involves nonself-announcing failures, such as those in rarely used safety subsystems. An example is the emergency brake on a car. Such failures can be difficult or tedious to test for because of the complexity of system behavior. If the test involves putting the item in a potentially unsafe condition, it is essential that provision be made to return the item to a safe condition before it can be operated.

5-2.2 ELECTRONICS, ELECTRICAL, AND ELECTROMECHANICAL

Many failures in this category are actually mechanical failures of an item serving an electrical function. For example, a printed circuit board can crack, or a wire can break in two. Some of such failures are testable as discussed in subpar. 5-2.1 and are not discussed in this paragraph. The discussion that follows is organized according to the four simple models for failure presented in subpar. 5-1.3:

1. *Simple Stress-Strength*. Most failures in this category involve electrical breakdown due to a large electrical pulse. The portion of the item that breaks down is usually an insulator, dielectric material, or a special layer inside an active electronic device. Items connected to wires that go

outside a building can receive severe electrical stresses due to lightning. Modern, complex semiconductors are generally susceptible to electrical overstress and/or electrostatic damage. Testing whether such items are sufficiently protected against their environment is not easy although it is generally easy to find an item that has failed because of such stress. An electrical proof test (analogous to the mechanical proof test) or a simple Go/NoGo functional test can be used to assure that the item is good. Two major problems are to be able to access the terminals of a device and, when that is done, to be sure that the test voltages do not harm adjacent devices.

2. *Simple Damage-Endurance.* This is the type of failure about which most electronic failure rate models are concerned. In many situations this kind of damage can be difficult or even impossible to detect before failure occurs. Damage can accumulate in dielectrics due to ordinary electrical stresses. Mechanically, things such as fuses can accumulate low-cycle fatigue damage due to thermal expansion and contraction.

3. *Simple Tolerance-Requirement.* In analog circuits this is a very common failure mode that can be tested reasonably well if the appropriate terminals can be accessed. For example, the gain of a radar receiver can be measured. Digital circuits are much less affected by drift, but it can occur. It is often necessary to be concerned about not only whether an item is within the requirement but also how large the safety margin is. When used as a conducting wire, aluminum can corrode (oxidize) and eventually acquire a strong insulating coating at a junction; this is a well-known phenomenon of aluminum electrical wire. Fault isolation is difficult in complex systems, especially when such systems contain computer software.

4. *Simple Challenge-Response.* This is the most common failure mode of computer software. It also applies to systems that are so complex they are impossible to test completely, e.g., automatic telephone switching systems. Testing before the failure is very difficult because the state of the system is a function not only of the current environment but also of the use history of the system.

5-2.3 HYDRAULICS AND PNEUMATICS

Failures in hydraulic and pneumatic systems can be classified as being in the fluids themselves or in the lines, valves, and other mechanical equipment that carries or uses the fluids. The discussion that follows is organized according to the four simple models for failure presented in subpar. 5-1.3:

1. *Simple Stress-Strength.* This failure model is inappropriate for the fluids themselves but can apply to the pumps, lines, receivers, and pressure vessels that carry the fluids. The discussion in subpar. 5-2.1 applies to such items.

2. *Simple Damage-Endurance.* This failure model does not apply at all to pneumatics, and it applies only indirectly to hydraulic fluids because they can carry particles that have been worn from the mechanical items with which the fluids are associated. Designing tests for this situation is straightforward.

3. *Simple Tolerance-Requirement.* Hydraulic fluids can degrade in terms of viscosity and lubricity. Hydraulic or pneumatic fluids can carry contaminants that harm their own function or the function of the mechanical items with which the fluids are associated. Thus filters are often installed to remove those contaminants from the fluids. Designing tests of the fluids and the filters for such failure modes is straightforward.

4. *Simple Challenge-Response.* This failure model is inappropriate for the fluids themselves, but it can apply to the systems that depend on the fluids for operation. The discussion in subpar. 5-2.1 applies to such systems.

5-2.4 OPTICAL AND ELECTRO-OPTICAL

All optical systems are also mechanical systems, and the discussion in subpar. 5-2.1 applies to them. The discussion that follows is organized according to the four simple models for failure presented in subpar. 5-1.3:

1. *Simple Stress-Strength.* Insofar as the items are optical lenses or electronic components, the discussions in subpar. 5-2.1, "Mechanical", and subpar. 5-2.2, "Electronics, Electrical, Electromechanical", apply to them. Otherwise, this model of failure does not apply.

2. *Simple Damage-Endurance.* The comments in "Simple Stress-Strength" from subpar. 5-1.3 apply here as well.

3. *Simple Tolerance-Requirement.* Optical lenses and fibers can degrade by scratches, removal of essential surface coatings, acquiring unwanted surface coatings, or becoming more opaque. Unless such degradation is obvious to the eye, elaborate test equipment is necessary to measure the degree of such degradation.

4. *Simple Challenge-Response.* This failure model is inappropriate for the optical or electro-optical elements themselves, but it can apply to the systems that depend on such elements for operation. The discussion in subpar. 5-2.1 applies to such systems.

5-3 TECHNOLOGIES OF TESTING

The influence of innovation and the categories related to testing are explained in the following subparagraphs.

5-3.1 INFLUENCE OF INNOVATION

The very concept of "test and testing" changes as technology changes. The ability of complex machines to measure and take corrective action (based on those measurements) on a product continuously while it is being made and without the intervention of people is very different from what it was a few decades ago, and of course it has been changing steadily since the 1920s. For example, during the 1960s the statistical quality control leaders invented the phrase, "You cannot test quality into a product!". The meaning of that statement, of course, depends on the definition of test. The statement never was true; it was a surrogate for "A process should be controlled as far upstream as feasible.". Selective assembly and sorting of product, for example, have always been the economic ways to control the quality of some products.

The tests that engineers consider for a discardable item are usually identical to those for a repairable item; the major difference is that at the end of testing a discardable item is not repaired.

5-3.2 CATEGORIES

Several categories of testing, test equipment, and test philosophy are defined. Their advantages and difficulties are explained briefly. The categories are not necessarily mutually exclusive, or even meaningful—especially as technology innovation occurs.

1. *Automatic Test Equipment (ATE).* "Equipment that is designed to conduct analysis of functional or static parameters to evaluate the degree of performance degradation and may be designed to perform fault isolation of unit malfunctions. The decision making, control, or evaluation functions are conducted with minimum reliance on human intervention." (Ref. 1) System complexity is often such that ATE is the only feasible alternative for testing.

a. Advantages. ATE requires less skill and fewer written test procedures and is generally faster than multipurpose test equipment.

b. Disadvantages. ATE is generally more expensive when averaged over the systems it can handle and more specific to a particular system than is multipurpose test equipment. ATE requires (1) a costly test program set (TPS), software development, and life cycle support, (2) update as product configuration changes, (3) configuration control beyond form, fit, and function, viz, to the piece-part or board level, and (4) keeping the TPS updated. There are problems in distribution, media storage, and documentation. Numerous TPS software versions must be fielded at the same time to support various configurations of the same system.

2. *Built-In Test (BIT).* "A test approach using built-in test equipment (BITE) or self-test hardware or software to test all or part of the unit under test." (Ref. 1)

a. Advantages. Many BITs, especially those involving self-test, are relatively simple, cheap, reliable, and effective and can cover many of the predictable problems. Generally, personnel at a lower skill level can perform the diagnosis.

b. Disadvantages. If the BIT is not comprehensive, it can give a false sense of security to the operator. BIT traditionally has not been applied to nonelectronic items. BIT adds its own weight, volume, cost, power requirements, and unreliability to the equipment it serves. Thus it can appreciably degrade the very equipment it is supposed to improve. This fact was overlooked in the early enthusiasm about BIT.

3. *Built-In Test Equipment (BITE).* "Any device which is part of an equipment or system and is used for the express purpose of testing the equipment or system. BITE is an identifiable unit of the equipment or system." (Ref. 1)

a. Advantages. Fewer test facilities and personnel are required. See also the advantages under ATE.

b. Disadvantages. See the disadvantages under BIT, Item 2b.

4. *Functional Test.* "Functional test" is a qualitative term. It generally checks the overall performance characteristics of an item under benign conditions and with benign criteria for pass or fail (Go/NoGo). For further discussion, see par. 5-4.

5. *Performance Margin.* The performance margin shows how close a performance characteristic is to being unsatisfactory. For example, if 0.60 mm of wear is allowed in a particular part and 0.50 mm has occurred already, the performance margin is 0.10 mm. It is an important concept in estimating mission reliability.

6. *Self-Test.* "A test or series of tests, performed by a device upon itself, which shows whether or not it is operational within designed limits. This includes test programs on computers and automatic test equipment which check out their performance status and readiness." (Ref. 4) Self-test is a subcategory of BIT; see the comments under BIT.

7. *Test, Measurement, and Diagnostic Equipment (TMDE).* "Any system or device used to evaluate the operational condition of a system or equipment to identify and isolate or both any actual or potential malfunction." (Ref. 1)

8. *Multipurpose Test Equipment.* A subset of TMDE that can be used for many purposes. It is generally manually controlled by the operator who follows written test procedures. The electrical multimeter and the oscilloscope are common examples of multipurpose test equipment.

a. Advantages. It can be used with a wide variety of test procedures on many kinds of items, i.e., it is reasonably universal. When its cost is averaged over the many kinds of equipment it can service at the DS, GS, or depot level of maintenance, it can be much cheaper. Manually controlled tests can provide flexibility that is not feasible to program into ATE software.

b. Disadvantages. For some testing it requires greater personnel knowledge and skills to be used effectively. At the unit level of maintenance it can be more expensive than special purpose ATE because of the wide variety of equipment and more highly skilled personnel than usually needed.

9. *Test Procedure.* "A document that describes, step by step, the operation required to test a specific unit with a specific test system." (Ref. 1). The word "document" should be interpreted broadly to include a written document, a com-

puter software program, a hardwired computer program, and any combination of these.

5-4 FUNCTIONAL TESTING

A functional test is "A test which determines whether the UUT [unit under test] is functioning properly. The operational environment (such as stimuli and loads) can be either actual or simulated." (Ref. 1).

Functional testing is also a qualitative term whose meaning changes with the technology innovation. This point is discussed in more detail in subpar. 5-3.1. It generally means the least costly* test of a nominal function, e.g., Does an amplifier amplify? Does a logic gate give the correct output for a set of inputs? Does an engine run at a reasonable speed with a modest load? Does hydraulic fluid pass through an operating hydraulic pump?. It is a test, not for the purpose of finding a failure, but for the purpose of finding a success. It is traditionally a Go/NoGo test that sets a minimum standard of performance; that is, if the item "tests bad", there is little reason to expend any more resources on testing it at that maintenance level. Further testing can, however, be performed at a higher maintenance level.

The effectiveness of functional testing depends on how well the system has been divided into modules for testing. Functional testing is generally appropriate for and only for the tolerance-requirement model of failure described in subpar. 5-1.3.

The advantages of such functional testing are that it is usually cheaper in terms of test time, test equipment, and testing skills (both in terms of running the test and in understanding the results). It applies to all types of systems and technologies.

The disadvantage of functional testing is that traditionally it does not indicate any performance margins, although it might use such information in arriving at the test result. It is generally difficult to use Go/NoGo information to estimate the mission reliability of the system or to prepare for corrective action. If the item is designed for discard, corrective action in terms of field repair does not apply, and corrective action in terms of production or engineering design is lost unless the nonconforming item can be analyzed internally and the information returned to an appropriate manufacturing or engineering design group.

5-5 FUNCTIONAL GROUPING

Most mechanical systems are physically grouped by function because there is rarely any other feasible way to lay out the system. When such functional grouping is not feasible, the system is usually awkward, and design ingenuity is called upon to use other technology to overcome the disadvantage. For example, the four wheels of a vehicle are not close together. Electrical and hydraulic subsystems are sometimes used to furnish power to the drive wheels.

Most electronic systems are likewise physically grouped by function because the system is easier to lay out that way, especially when some of the functions are in separate physical modules, e.g., a power supply.

One of the advantages of electrical, electronic, hydraulic, and pneumatic systems is that the elements need not be physically grouped. In fact, the major appeal of these types of systems comes from the ease with which energy can be converted to and from them, and their energy can be transmitted and controlled.

Any kind of diagnostic procedure is more simply performed on a single module than on multiple modules physically dispersed throughout the end-item. Diagnostics are more effectively performed on functional modules than on modules that contain parts of many functions. These two forces determine in large part the way designers lay out systems (software or hardware) and procedures for system test.

The preceding analysis is complicated by the way designers and users view the concept of function. Many items can be considered to have several functions, e.g., the front axle and wheel combination on a front-wheel-drive car.

5-6 APPLICATIONS AND IMPACTS

Examples are given for each of four categories: mechanical; electronics, electrical, and electromechanical; hydraulics and pneumatics; and optical and electro-optical. Rarely is a usable system in only one of these categories. For example, all systems have components that serve a structural (mechanical) purpose, many systems contain electromechanical devices, most testing uses electronic or electrical devices, and all devices—except static structures and some electro-optical items—generate heat that must be removed to keep the temperature of the device low enough. Thus no example is a pure case of the category in which it appears. Each example is discussed under the following headings: testability, test philosophy, functional testing, and functional grouping. These headings relate to the previous paragraphs in this chapter with similar titles.

5-6.1 MECHANICAL

Consider the propulsion* system of an automobile. Such a system includes an ordinary internal combustion, carbureted gasoline engine; a transmission (including the clutch); a coupling mechanism, e.g., driveshaft, differential, and rear axles; wheels; and the brake-actuating mechanism.

1. *Testability*. Test-stands for the propulsion system as a whole are expensive and large; thus they are suitable only

*A "least costly" test today might have been virtually impossible a decade ago. That is why defining "functional" test is so difficult and arbitrary.

*Propulsion is used in its general sense to mean the system in which energy is generated, transmitted, stored as potential energy (e.g., dynamic braking for which the propulsion motor becomes a generator), and converted to heat. This usage is common, for example, in transit system vehicles.

at the depot maintenance level. An experienced driver or the user maintenance level can usually isolate the trouble to a major subsystem by observing the type of nonperformance or the noise and vibration signature. If the problem is the engine, a few simple tests at the user maintenance level can often isolate the trouble to one of the subfunctions of the engine, e.g., the fuel system. For ordinary performance characteristics such a propulsion system is quite testable without expensive test equipment or special design features for testability.

2. *Test Philosophy*. The traditional propulsion system (up through the 1970s) had no BIT or BITE, and the ATE for it was virtually nonexistent. Some of the engine subfunctions are continuously monitored, e.g., the charging rate of the alternator (generator), the temperature of the cooling fluid, and the speed of the engine. Although not very modern, those monitors come very close to being included in the definitions of BIT and BITE. In the 1980s the newer transducers being used to monitor some of the engine functions could perhaps be called BITE. Regardless of their terminology, they have made ATE more feasible for the engine. The test philosophy on the remainder of the propulsion system remains essentially as it has been for decades.

3. *Functional Testing*. Functional testing is done by the operator, who uses the ordinary operator controls as inputs, the human senses to detect the output, and experience to evaluate the output. The function to be tested can be the system; some of the subsystems, e.g., the engine or a wheel; or some elements of some subsystems, e.g., an alternator or power steering pump. A maintenance technician performs similar tests except that inputs are extended by some test equipment and by direct access to a subsystem, detectors are extended by the built-in sensors of the engine or some test equipment, and evaluation is extended by the indicators on test equipment or by instructions in a technical manual.

4. *Functional Grouping*. Mechanical functions are generally grouped because grouping is the nature of mechanical systems. The items that are not grouped must use shafts, axles, or chain drives, e.g, the driveshaft; fluid tubing, e.g., the braking system and cooling the transmission; pneumatic hoses, e.g., a vacuum hose; or electrical wires. We are so used to automobiles that we often do not think of them in these terms—we just believe everything is where "it belongs".

5-6.2 ELECTRONICS

Consider electronic equipment that contains computer hardware and software, other electronic assemblies, a microwave subsystem, some power output subsystems, and a variety of power supplies for all of the subsystems.

1. *Testability*. Testability is important during both manufacture and field use. Digital electronics is one of the major technologies in which quality must be inspected-in during manufacture either by sorting a population (removing the bad parts) or by repairing an assembly.* The testing support hardware must be designed at the outset. Advances in technology allow integrated circuits and printed circuit boards to become so small and densely populated that their testability is a limiting factor in being able to use that advanced technology. Electronics designers usually have received little or no education in reliability and maintainability, and they have a difficult enough time meeting the traditional performance requirements within the cost, schedule, volume, and weight constraints. Test engineers have a variety of techniques and technology available with which to increase the testability of electronic equipment. For example, special test points on a printed circuit board can be brought out to edge connectors for use during testing, and design engineers tend to provide a specific function, such as a power supply, in a module that is reasonably testable. As manufacturing technology improves, several device technologies can be placed onto one circuit board as a single function—thus the testing function is complicated. Such kinds of technology include analog devices and several digital technologies. Each technology has its own limitations in terms of types and frequencies of signals and magnitudes of allowable voltages, currents, and power. Such decreases in testability tend to be met by smarter test equipment, and proper testability planning during the design phase of microcircuits and circuit boards improves their testability. Design engineers need an incentive to work with test engineers during the design and development of equipment rather than to present the test engineer with a virtually complete design. One of the aims of concurrent engineering is to encourage such cooperative team work.

2. *Test Philosophy*. The technology of testing is changing rapidly. Current multipurpose equipment can have automatic features that formerly were not even available in specialized test equipment. In digital technology, especially in memories, BIT is common and is usually implemented largely in software. The output of power supplies can similarly be tested. BITE can be used for more complete, parametric testing—as opposed to functional testing—and has been traditionally necessary in order to implement BIT for technologies, such as microwave and analog signals. What can or cannot be done in electronic testing changes because the technology changes—even before the testing and support equipment and documentation can be widely disseminated. For example, testers are becoming available that can handle mixed analog and digital technologies. The move to standardize ATE is well intentioned but difficult to implement. Such things as VAST (versatile avionics shop tester) and MATE (modular ATE) are good ideas but are difficult to

*The best yield for microcircuits, for example, is about 95%; thus the bad 5% are removed by testing (screening) all parts. The drive to make microcircuits better and cheaper prevents the yield from being higher.

perfect and to enforce. Enforcement difficulties arise because designers tend to resist much standardization because they tend to believe that standards restrict their choices, can be an unworkable compromise, and can be outmoded by new technology before they are even promulgated. Again, concurrent engineering shows all the engineering groups it is really easier for all of them to do better jobs if they work together as a team. BITE, if used, must be integrated with the system during design and development and be included in the system constraints of reliability, maintainability, schedule, and cost. In combined hardware and software systems it can be very difficult to isolate a failure to the software or the hardware exclusively; failure of either one can give very similar symptoms.

3. *Functional Testing*. Functional testing is reasonably effective and straightforward for electronic modules, at least where device technologies are not mixed. For microwave waveguides, for example, it might be worthwhile to have submodules that are reasonably compact and functionally testable. BIT generally is a functional test.

4. *Functional Grouping*. Unless there is a compelling reason not to, design engineers generally group elements together that are part of a function. The key to this rule is the concept of "function". For example, electrical meters for display are generally placed on the front panel because their common function is to display the state of the system. Each meter, however, might display the state of disparate electrical functions of the system. Some reasons for not grouping by electrical function are size, weight, power dissipation, cooling needs, design for discard, visibility to the operator, and need for shielding because of high voltage or electromagnetic emissions (incoming or outgoing). When an item can be classified as one of several functions, it is not clear exactly what "functional grouping" means. For example, if the microwave subsystem requires a separate high-voltage power supply, is that power supply grouped with the "power supply" function or the "microwave" function? Because of the strong incentives to reduce size and weight of electronic items, the electronics industry is forcing functional grouping by simply putting a functional group in one package and calling that package a component. For example, a single integrated circuit for a computer is available that combines the functions of many integrated circuits of just a year ago.

5-6.3 ELECTRICAL AND ELECTRO-MECHANICAL

There are very few electrical, nonelectronic items that are not also electromechanical—other than for resistance heating or the distribution of electricity—because there are mechanical functions involved. Consider a fractional horsepower, single-phase ac, capacitor-start electric motor, which is a very common electromechanical item, and an electric, single-phase ac generating system of moderate capacity, e.g., a few kilovolt-amperes.

1. *Testability*:

a. *Electric Motor*. The main elements that can fail are the windings (short to the frame, turn-to-turn short, or open), the starting capacitor (short, open, or high series resistance), the centrifugal switch (fail to open or fail to close), the bearings (excessive wear, loss of lubrication, fatigue pitting, or will not turn at all), and the housing (crack or warp). If the motor is a discardable module, it is reasonably easy to test; only an appropriate source of electric power and an adequate mechanical load are needed. The important characteristics of the electric power are its nominal voltage and its regulation (voltage, current, and load angle relationships). The important characteristics of the mechanical load are its inertia and its speed-torque relationship. If the motor is repairable, the ability to test its main elements for all of their failure modes is necessary. Some such tests can be done without taking the motor apart. Regardless of what kind of test needs to be performed, it is likely that only functional testing can be done at other than the depot level of maintenance.

b. *Electric Generating System*. The main subsystems are the generator, the engine, and the controls. The elements of the generating system that can fail are the controls, both frequency and voltage; the generator bearings, windings, and housing; and the engine (It is not considered in detail.). Testing the generator separately from the engine is difficult because the frequency control is essentially the speed control of the engine. The important steady state characteristics of the generating system output are its nominal voltage, its voltage regulation (voltage, current, and load angle relationships), its nominal frequency, and its frequency regulation. There are similar important transient characteristics. Measuring all of these things requires extensive instrumentation and electrical load controls. The engine, generator, and controls are likely to be separate modules. A generator of this size (several kVA) is not likely to be discardable, so its internal failure modes must be testable. Regardless of what kind of test needs to be performed, it is likely that only functional testing can be done at other than the depot level.

2. *Test Philosophy*:

a. *Electric Motor*. At the unit maintenance level the only test of the motor is generally, "Does the equipment have symptoms that are traceable to the motor?". If so, the motor is replaced, and the old motor is given a simple functional test. If the old motor fails that test, it is discarded. Otherwise, it is sent to the depot maintenance level for a more complete test. The only special test philosophy might be some ATE at the depot level that would apply to most fractional horsepower motors.

b. *Electric Generating System*. There is usually the BITE consisting of a frequency meter and a voltmeter to measure continuously the two important characteristics of the system. An ammeter and perhaps a wattmeter are desirable. Isolation of trouble to a subsystem (engine, generator, or controls) is usually done by the operator or a unit maintenance level person observing the behavior of the system. At the DS, GS, or depot maintenance levels, each subsystem is tested separately. ATE might be feasible at the depot maintenance level but is likely to be too costly at the DS and GS maintenance levels.

3. *Functional Testing*:

a. *Electric Motor*. The simplest test is to apply a voltage near the nameplate voltage and observe that the motor starts and runs smoothly. A more complex test would measure the input voltage, current, and power (All of which are reasonably inexpensive with a multipurpose instrument.) and would apply and measure a mechanical load near the rated load. However, applying that load is neither easy nor inexpensive. Basically there are two ways to apply a load in a test fixture: Apply friction to a rotating drum (Prony brake) or drive an electric generator, e.g., an induction motor driven over its synchronous speed. The first method converts the mechanical power into heat and thus requires that the heat be removed without an undue temperature rise; the second method converts the mechanical power into electrical power that can be fed into the electric lines.

b. *Electric Generating System*. The simplest test is to start the engine, apply a resistive nominal load, such as incandescent lights, and observe the voltage and frequency and glowing light bulbs. A more complex test would be to apply the maximum load (probably resistive) and measure the voltage, frequency, and power. A functional test on the generator alone could use an ordinary induction motor to drive the generator, perhaps with an adjustable ratio V-belt drive to bring the speed up to the proper value.

4. *Functional Grouping*:

a. *Electric Motor*. By its nature the motor is a single functional group of its elements. In use, however, the motor must be mechanically coupled to its load, and such coupling can be rather complicated, e.g., it can provide for torque smoothing and for shaft misalignment. The electric power must be supplied through some conditioning device; at a minimum a switch and overcurrent protection are needed.

b. *Electric Generating System*. The engine and generator functions are virtually always grouped functionally because that is the easiest and cheapest way to do it. The frequency control might be on the engine itself (a simple speed controller), or it might be a complex electronic feedback system. A complex feedback mechanism belongs to both the input and output functions, so the phrase "functional grouping" means little. For example, such a mechanism could have several sensors for its inputs, a mechanism to process those inputs, and an actuator as its output. The location of frequency and voltage controllers would also depend on the accuracies required. For example, for ±5% frequency accuracy the engine-speed controller would probably be an integral part of the engine, whereas for ±10% voltage accuracy the controller would probably be an integral part of the generator. For much better accuracies, e.g., 1/10 of those numbers, the controllers would probably be in modules external to the engine and generator. The implementation of those modules would depend on the technologies available at the time of design and manufacture.

5-6.4 HYDRAULICS AND PNEUMATICS

Consider a high-pressure hydraulic system and a compressed air system to start a diesel engine. Each system has a pump, fluid lines, a rotary motor, a supply of fluid, conditioners, and appropriate gages and controls. The hydraulic pump runs all the time and uses an analog control valve to adjust the speed and direction of flow. The air compressor fills a storage tank, which is maintained at a nominal, constant pressure. The primary power for each system is presumed to be available when needed and is not considered further.

1. *Testability*:

a. *Hydraulic System*. The important characteristics of the pump are internal leakage, external leakage to and from the outside, minimum no-flow pressure, minimum no-pressure flow, regulation (pressure vs flow relationship), and strengths of the mechanical parts. The important characteristics of the hydraulic lines and connectors are blockage, external leakage to and from the outside, and strength of the walls. The important characteristics of the motor are internal leakage, external leakage to the outside, and strength of the mechanical parts. The important characteristics of the hydraulic fluid are lubricity, gaseous impurities, corrosive impurities, abrasive impurities, and products of wear. The important characteristics of the conditioners are pressure drop, ability to remove foreign substances (given that there are no internal leaks), internal leakage, external leakage to the outside, and strength of the mechanical parts. The important characteristics of the gages are accuracy and sensitivity, readability, external leakage to the outside, and strength of the mechanical parts. The important characteristics of the controls are accuracy and sensitivity, not sending a signal when they should not, and sending a signal when they should. Finally, there is the environment in which the system operates. For example, that environment could be a mechanical object, e.g., an insulated wire, that rubs against (and thus wears) the hydraulic lines in a location that is relatively inaccessible to inspection. The pressures are readily testable by built-in gages. Blockage can be inferred from the pressure drop along the hydraulic lines and a flow meter, but flow meters are expensive and thus seldom used. Leakage is often not testable except by inspection; if the lines and connectors are not accessible, considerable undetected leakage can occur before the system performance degrades sufficiently to alert the operator. Without taking the system apart, anomalies that degrade the strengths are almost impossible to find, except for large cracks in readily visible parts. The metal parts have many different failure modes, e.g., corrosion, fatigue, wear, and work hardening.

b. *Air Starter.* The important failure modes and mechanisms of the air compressor (pump) are internal leakage, external leakage to the outside, flow at the nominal pressure, and strength of the mechanical parts. The important characteristics of the air lines and connectors are blockage, external leakage to the outside, and strength of the walls. The important characteristics of the starter motor are internal leakage, external leakage to the outside, lubrication of the bearings, and strength of the mechanical parts. The important characteristics of the air are corrosive impurities and abrasive impurities. The important characteristics of the conditioners are pressure drop, ability to remove foreign substances (given that there are no internal leaks), internal leakage, external leakage to the outside, and strength of the mechanical parts. The important characteristics of the gages are accuracy and sensitivity, readability, external leakage to the outside, and strength of the mechanical parts. The important characteristics of the controls are accuracy and sensitivity, not sending a signal when they should not, and sending a signal when they should. Finally, there is the environment in which the system operates. For example, the surroundings could be extremely dusty and clog the intake air filters or could contain corrosive chemicals that would damage the metal parts of the entire system. Pressure is relatively easy to measure with a gage. It is not necessary to observe other secondary performance characteristics because the overall performance of the system is readily determined by an alert operator. The storage tank is a pressure vessel whose construction and safety are governed by various codes. The strength of the parts is usually difficult to determine without extensive inspections, and in many cases such inspections are not worth what they cost, e.g., it would be cheaper to replace suspect parts.

2. *Test Philosophy*:

a. *Hydraulic System.* BITE consisting of pressure gages is generally used. Flow gages are not used as often because they are much more expensive. If blockage of the lines is a common problem, pressure drop from end to end can be measured with simple gages and/or equipment. Specialized test equipment would be rare at unit level maintenance and DS and GS levels of maintenance. At depot level maintenance there would be ATE or semiautomatic test equipment to check performance of pumps, conditioners, and motors. It is not likely that expensive equipment, like Magnaflux™, would be used to check for fatigue cracks. If a pump or motor were taken apart, it is likely that a standard list of repairs would be made, for safety reasons if nothing else. The basic failure modes and testing methods for this kind of equipment probably have not changed much in several decades.

b. *Air Starter.* BITE consisting of a pressure gage on the storage tank is all that there is likely to be. Valved test points might be available to check pressure at other points. This type of equipment is common enough that multipurpose test equipment is likely to be available at DS and GS levels of maintenance. The basic failure modes and testing methods for this kind of equipment probably have not changed much in several decades.

3. *Functional Testing*:

a. *Hydraulic System.* The main functional test on the system is whether it works. A unit level maintenance person can readily perform the functional test. Repair would probably be by replacement of modules, such as a pump or conditioner. Unless there were many such systems in a particular area, the main modules would be sent to the depot level for inspection and repair or discard.

b. *Air Starter.* The main functional test on the system is whether it works. A knowledgeable operator can readily perform the functional test. Repair would probably be by replacement of modules, such as a pump, storage tank, lines, or starter motor. The main modules would probably be sent to DS or GS level maintenance for inspection and repair or discard.

4. *Functional Grouping*:

a. *Hydraulic System.* The pump and its gages can be grouped as a function. It is feasible to group the conditioning items as a function. By the nature of the system the pump and motor are not very close—that is the reason for converting mechanical energy to pressure energy and back again. It is feasible to consider the pump and conditioning items as a functional group with relatively cheap items or those that need preventive maintenance (gages and filters) as externally replaceable on the module.

b. *Air Starter.* The pump, conditioners, storage tank, and motor are all located according to function and feasibility, e.g., the pump is located where it can be driven by an engine belt, the conditioners are located where there is adequate space and where they are accessible for preventive maintenance, the storage tank is located where there is space, and the motor is located wherever the direct drive to the engine is feasible. Thus, as in other energy conversion devices, functional grouping of the system is generally impossible because that is why the energy conversion device was used, i.e., to choose a conveniently transmissible form of energy.

5-6.5 OPTICAL AND ELECTRO-OPTICAL

This is a relatively new and rapidly developing field. Most of the research and development is being done in the commercial sector, and as in other portions of the commercial sector, many of the products are designed for discard simply because such designs are better and cheaper from the point of view of the manufacturer. Often the customers and users agree with these decisions. It is feasible for the Army to use the technology and discardability that the commercial sector provides.

Built-in indicators should always be provided for Go/NoGo status in order to verify the correct operation of the diagnostic equipment itself. Those indicators should generally be set up by the diagnostics to show a NoGo state; when the unit initializes, the indicators should switch to the Go state if the unit is functional.

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CHAPTER 6
PHYSICAL ARRANGEMENT

Physical arrangement and its relationship to design for discard is covered by discussing modular construction and access for maintainability and by explaining the several kinds of partitioning: spatial, functional, similar part, reliability, cost, and testability. Hypothetical examples are given to illustrate the ideas.

6-1 INTRODUCTION

A design engineer would put everything in the system close together, no matter what the item, if that were feasible, simply because the design process would be less complicated and many of the connecting items, e.g., wires, tubing, shafts, and connectors, could be eliminated. In general, everything cannot be close together, if only because there is simply not enough space. Thus the design engineer must make feasibility tradeoffs while deciding where to put everything, i.e., what the physical arrangement will be.

The feasibility tradeoffs can be put into three general categories: design and manufacture, operation, and maintenance. A tradeoff need not be in one category exclusively; indeed, the designer can face tradeoffs between and within categories. The three categories are

1. *Design and Manufacture*. This category is generally concerned with item characteristics such as electronic-signal delay, weight, volume, heat generation, heat sensitivity, shock or vibration sensitivity, and/or physical and chemical contamination or purity. Physical manufacturing problems are reflected in the design. Examples are

a. The vacuum accumulation tank in a car engine is put wherever there is adequate space and is connected to the appropriate devices by rubber hoses.

b. The power supply for an electronic item is placed close to the heat sink.

2. *Operation*. This category is generally concerned with the function of the item during its use and is often related to the man-machine interface and the convenience of the operator. Some items perform widely disparate functions. Examples are

a. The transmission-oil cooler in a car is in front of the radiator so it can get cool air, and it is connected to the transmission by steel tubing.

b. Meters that an operator must observe are placed where the operator can see them during ordinary operation and are connected to the appropriate sensors by wires, hoses, or tubing.

3. *Maintenance*. This category is generally concerned with improving the maintainability or complying with some maintenance requirements. Examples are

a. Electric fuses are often put on the front panel and are connected to the internal power lines by wires.

b. A module that must often be discarded or preventively maintained is placed where access is relatively easy.

Various physical arrangements are feasible because electrical, hydraulic, and pneumatic systems can be used to convert to and from mechanical energy. Choosing a conversion system involves tradeoffs among the physical arrangement and the ease with which the energy, power, force, and/or torque can be transferred from physical location to location. Tradeoffs about such systems can affect, or be affected by, the physical arrangement, discardability of modules;

1. *Energy Transmission*. Transmitting electrical, hydraulic, and pneumatic energy, as opposed to mechanical energy, can be more convenient and cheaper. That is, when the transmission path is complex or long enough, wires or fluid lines are much cheaper and more convenient than mechanical shafts, couplings, gearboxes, and/or chain drives.

2. *Torque-Speed Characteristics*. Electrical, hydraulic, and pneumatic motors (items that convert the transmitted energy to mechanical energy) have a wide variety of torque vs speed curves—between the general categories and within each category. This feature provides the designer the flexibility to choose a system and physical arrangement that best meet the system requirements.

Chapter 10, "Analysis and Decision Techniques", explains the several categories of techniques and models for analysis of costs (tradeoff, level of repair, and front end).

6-2 MODULAR CONSTRUCTION

Modular construction is useful not only in its own right but is also an essential element of the design for discard philosophy. The major advantage of a module in design for discard is that the cost associated with its replacement can be appreciably less than the alternatives of replacing a group of items or removing an item from a larger module of which it is an integral part. A set of items to be discarded as a whole (when failed) should be a module. Six partitioning methods—spatial, functional, similar part, reliability, cost, and testability—are discussed in pars. 6-4 through 6-9.

Definitions of "module" and "modular design" follow:

1. *Module*. An item, assembly, subassembly, board, card, or component that is designed as a single unit to facilitate and simplify production line techniques, transportation, supply, and maintenance processing (adapted from Ref. 1)

2. *Modular Design*. A modular building block principle that normally employs quick-disconnect features and is the method used by materiel developers to simplify design-

and construction and to improve fault diagnosis, replacement, and repair of suspect systems (adapted from Ref. 1).

As used in this handbook, *partitioning* is the physical grouping of some items of a system according to a set of rules with the intent that some particular groups will be modules. A name is often given to the set of rules and its intent, and that name is used to modify "*partitioning*", e.g., cost partitioning. Partitioning is part of the design and is involved in the tradeoffs made during the design and development of an item. There are three directions in partitioning:

1. *Aggregation*. Collecting some items that would otherwise not be placed with each other
2. *Segregation*. Separating some items that would otherwise be placed together
3. *Pseudosegregation*. Making a part readily separable or removable from a module, but otherwise leaving the module intact.

6-3 ACCESS

Access is an element of ease of maintenance. From a maintainability standpoint the ease of access of modules should be better for the modules that are likely to be replaced more often. This general principle also applies to discardable modules. The phrase ease of access* includes the following factors:

1. It should be easy for maintenance personnel to get to the suspect item, to remove it, to install the replacement item, and to return the system to a nondefective state.
2. It should be hard for maintenance personnel to injure themselves or harm the environment during maintenance.
3. It should be hard to damage the suspect item further while removing it or the replacement item while installing it.
4. It should be hard to damage good items that must be removed and replaced during access, and it should be hard to replace those items improperly.
5. It should be hard to damage surrounding items that are not directly involved in the maintenance action.

As with all principles, these must be traded off with each other for all items in the system and with other principles such as system reliability, maintainability, and modular design.

6-4 SPATIAL PARTITIONING

Spatial partitioning is related to space, e.g., volume, shape, or location of items. Spatial partitioning is used when

1. An item will not fit in the desired location; therefore, it is located where it will fit.
2. An item will not fit in the desired location; therefore, its shape is changed so that it will fit.
3. An item will not fit in the desired location; therefore, it is split into several parts that will fit.
4. An item is put into a particular location because of the local environment at that location. Such environments include
   a. Lack of electrical noise, whether conducted or radiated
   b. Shielding against leakage (conduction or radiation) of electrical signals and noise to the outside
   c. High heat conductivity to a heat sink
   d. Temperature not too high, e.g., does not exceed 40°C (104°F)
   e. A regulated temperature
   f. Low vibration and shock
   g. Cleanliness (absence of dirt and other particles)
   h. Control of chemicals, e.g., an inert or oxidizing atmosphere.

6-5 FUNCTIONAL PARTITIONING

Functional partitioning** is partitioning whose rules are related to the functions of the items being partitioned. It is the partitioning that designers use unless there is some reason not to because it is the simplest, cheapest way to lay out a system.

There is not a one-to-one correspondence between functions and items. Many items can be considered to have several functions, e.g., a wheel on a vehicle, and many functions can be considered to have several subfunctions, each provided by a separate item. Thus the concept of functional partitioning can be complicated.

Electrical, hydraulic, and pneumatic systems have elements that need not be physically grouped in order to provide a function. The major appeal of these types of systems is due to the ease with which mechanical energy can be converted to and from them and the fact that their energy can be transmitted and controlled.

For more information on functional partitioning, see par. 5-5, "Functional Grouping".

6-6 SIMILAR-PART PARTITIONING

Similar-part partitioning is partitioning related to having similar types of parts put together. Similarity, however, is in the eye of the designer. For example, parts can be similar because they are all pumps or all resistors or all dissipate large amounts of power or all operate from the same mechanical power source.

The main uses for this type of partitioning are to facilitate preventive maintenance, e.g., when one of the similar parts fails, all of them are replaced because they all have a similar

*Ease of access can be generalized to: It should be easy to do the right thing and hard to do the wrong thing.

**Functional partitioning is "The physical or electrical separation of system or unit elements along interfaces which define and isolate these elements on the basis of function or purpose." (Ref. 2).

life span, or to implement spatial partitioning so that each part can have its special environment, e.g., a low-temperature, low-humidity atmosphere.

6-7 RELIABILITY PARTITIONING

Reliability* partitioning is partitioning related to the reliability of the items. From a practical viewpoint items whose reliability is presumed to be similar would be put into a module. This type of partitioning is used because it can be costly to throw away parts that have a lot of life left in them.

Reliability is often measured by the average life of a group of items. Thus reliability partitioning is implemented by putting items with similar average lives in the same module and those with disparate average lives in separate modules. There can be correlations between reliability and cost or reliability and similar parts. Because of such correlation, cost partitioning or similar-part partitioning could turn out to be reliability partitioning.

For nominally alike parts there is often much statistical scatter in individual lives around their average life. For example, making the common assumption of constant failure rate, let the average life be 10,000 h. Then 10% of the lives will be less than 1000 h and 10% of the lives will be more than 23,000 h. Before reliability is used as a basis for changing the physical arrangement, the scatter among individual lives in each partition must be determined, and there should be negligible overlap of individual-part lives between the different parts in the different partitions.

6-8 COST PARTITIONING

Cost partitioning is partitioning related to the costs of items, i.e., only those failure-prone items with similar cost are placed together in a module. This philosophy is useful, for example, if there are many relatively inexpensive items in a subsystem and very few expensive ones. That is, each expensive item is one module, and the collection of inexpensive items is in another module. Any of the modules are candidates for discard.

6-9 TESTABILITY PARTITIONING

Testability partitioning is partitioning related to the testability of the items in a single module; it can be similar to functional partitioning. If a collection of items can be tested with the same test equipment and test setup, there is reason to want to place them into one module. This type of partitioning most likely would be used to segregate an existing module further for testability reasons. If the gross testing cost is a major part of the module cost, testability partitioning is an important design alternative to try.

*Reliability is a complicated subject because it is closely related to probability and statistics and because it is generally difficult and costly to measure. For example, individual items do not have a reliability; only a population of items has a reliability. As with other topics, such as heat transfer, shock and vibration, and materials properties, experts in the field should be consulted.

6-10 APPLICATIONS AND IMPACTS

Examples are given for each of five categories: mechanical, electronics, electrical and electromechanical, hydraulics and pneumatics, and optical and electro-optical. It is rare for a usable system to be in only one of these categories. For example, all systems have components that serve a structural (mechanical) purpose, many systems contain electromechanical devices, most testing uses electronic or electrical devices, and all devices (except static structures) generate heat that must be removed to keep the temperature of the device low enough. There are no examples of systems in just one category.

Examples are discussed under the headings: spatial partitioning, functional partitioning**, similar-part partitioning, reliability partitioning, cost partitioning, and testability partitioning. These headings relate to the previous paragraphs with similar titles in this chapter. Examples of partitioning types are given within a subparagraph only for those types that directly apply to the category of that subparagraph.

6-10.1 MECHANICAL

"Mechanical" here refers mainly to structural items or the structural aspects of items or to items that provide or transmit physical motion. Similar-part, reliability, cost, and testability partitioning are not used because mechanical systems are used for structures and power transfer. Spatial and functional partitioning are usually the only feasible kinds of partitioning.

1. *Spatial Partitioning*. Most such partitioning is segregation and is rarely used for discardability. A heavy item should be located below the center of support† of its system so the system will not tip over easily. Heavy items in a vehicle are generally located in the suspended portion of that vehicle to minimize the unsprung weight, even though it makes the drivetrain more complex. The four wheels of an automobile are part of the propulsion and braking systems, yet they are located far apart. Such location complicates the drivetrain and braking system. The fuel storage tank in a vehicle is located away from the engine for safety and convenience.

2. *Functional Partitioning*. This is the usual method that designers use to create modules unless there is a compelling reason to do otherwise. If functional grouping is not feasible, the system is usually awkward. If such grouping is too awkward or costly, design ingenuity is called upon to use other technology to overcome the disadvantage. A single general function can include dissimilar functions, e.g., a

**Functional partitioning is the usual method that design engineers use to create modules unless there is a compelling reason to do otherwise.

†This is not the same as the center of gravity.

fuel system on a vehicle includes a storage tank, fuel lines, a pump, a system to deliver the fuel to the cylinders, and a gage for the storage tank. This example demonstrates that functional partitioning is a general, approximate concept, not a rigorously defined one.

6-10.2 ELECTRONICS

Electronic items that are associated with a given function are generally grouped as close together as feasible. Different varieties of circuits and components, such as analog and digital, could not be manufactured with the same silicon technology (at least not during much of the 1980s). Physically large and/or heavy components, such as high-inductance elements, could not be placed on the silicon chips, but they needed to be physically separated from them for integrated circuits. As technology changes, the designs change to use the things that are easier to do and to avoid the things that are difficult to do. Also the things that are easier to do can themselves change. Thus it is impossible, especially in electronics, to state what will be feasible in the next few years. This is one of the areas in which system designers use what the current component technology can provide.

Some items must be segregated because of their effect on other parts or their sensitivity to the environment.

1. *Spatial Partitioning*. Discardable modules should be easily accessible, but sometimes an electronic item must be packaged in a shape that is determined by the space available for it, e.g., items that must fit into the fuze of an artillery projectile. Shielded enclosures are often used to protect circuits from a radio-frequency, electromagnetic environment and vice versa. Because such enclosures are costly and consume volume, disparate parts that need such protection are put into the enclosure to segregate them from the rest of the system. A similar situation exists for a constant temperature enclosure. An electronic chassis is often laid out with heat transfer and the signal path in mind. Heat transfer is a problem that traditionally is easy for electronics engineers to overlook. The opposite of locating items where they will fit can also occur, especially in very high-speed circuits. At most, an electronic signal can move 0.3 m (1 ft) in 1 ns; thus if time delays in the range of 0.1 to 1 ns are important, the items involved must be kept very close together, regardless of any other considerations.

2. *Functional Partitioning*. Function is generally considered to be the propagation and transformation of signals or the provision of controlled power at several voltages and currents. This is the most important type of partitioning for electronics, especially since the functions that can be economically performed by electronic systems have been expanding rapidly for decades. Thus the other types of partitioning are useful only if they do not intérfere with function. With an emphasis on human factors, the operator functions such as reading meters, manipulating switches, and changing fuses must also be considered. The trend in electronics packaging whether on a single chip, a substrate, or a printed circuit board is to aggregate functionally similar parts as much as technically feasible in order to reduce total cost and to improve reliability and performance. Such cost reduction can mean that the new module containing more functions is a better candidate for discard.

3. *Similar-Part Partitioning*. This partitioning occurs in electronics when, for example, fuses are put near each other and/or panel meters are put near each other. The prime reason for doing so, however, is usually something else, such as human factors or ease of testing and servicing.

4. *Reliability Partitioning**. The reliability of electronic items is usually measured by the mean (average) life of a population of similar items. Insofar as it is feasible to know the mean lives of various electronic parts, parts with very long mean lives can be separated from parts with very short mean lives. In that way, modules with long mean lives that contain components with long mean lives could be discardable because they will seldom fail. Modules that contain components with short mean lives could be discardable because no components with long mean lives would be needlessly thrown away. There are many pitfalls to such partitioning:

a. If the total number of leads in and out of the separated modules is higher, the combined reliability of those modules could be worse because connectors and removable connections are among the least reliable elements in electronics.

b. The manufacturing technology might be such that it is cheaper and more reliable to put all the components on a common substrate, such as a silicon chip or a printed circuit board.

c. The length of the leads connecting the separated modules might interfere with the combined performance of the separated modules.

d. If redundant modules are needed, e.g., for safety systems, physical separation could be important to reduce the probability of common cause failures.

5. *Cost Partitioning*. Cost partitioning can be effective as long as reliability, performance, and other important attributes are not degraded. For example, an expensive microprocessor on an otherwise inexpensive printed circuit board might be made removable so that when the revised printed circuit board fails, the microprocessor could be salvaged and used again. The disadvantage is that a relatively unreliable and costly connector** has been added to the

*A reliability statistician should always be consulted in this matter because many of the concepts involving mean life of electronic parts are difficult for managers and engineers to understand. Similarly, the economics and technology in electronics manufacturing are changing rapidly so that engineers and managers have to work and study very hard to stay current and to see a short way into the future.

**Adding a connector is more costly and much less reliable than the original uninterrupted wire or soldered connection.

system. It is quite possible that putting more components together on a common board or chip will decrease the cost and improve the reliability and performance sufficiently for the item to be discardable. The feasibility of separating low-cost parts from high-cost parts depends mainly on the type of system, e.g., analog audio-frequency systems or digital high-speed systems.

6. *Testability Partitioning*. Testability partitioning can be useful as long as reliability, performance, and other important attributes are not degraded. If combining items with similar testability into a single module would actually improve the testability of those items, that aggregation could be very helpful in a design for discard environment. Similarly, removing some items from a module that interfered with testability of the remaining items could also be very helpful.

6-10.3 ELECTRICAL AND ELECTRO-MECHANICAL

Electrical and electromechanical items are generally placed where it is convenient to do so, e.g., relays might be aggregated on a main board that is located for ease of maintenance, or where a mechanical function must be performed, e.g., motors are placed as close as feasible to the item being driven. For the mechanical function, functional partitioning is usually the only feasible method. For electrical functions the nature of transmission of electrical energy allows many types of partitioning. The flexibility allowed by the use of electrical energy can be a major factor in designing parts of systems for discard.

1. *Spatial Partitioning*. Spatial partitioning would rarely be used because functional partitioning is usually feasible.

2. *Functional Partitioning*. Functional partitioning is a very reasonable method to use in designing electromechanical items for discard. An alternator (generator) on a vehicle, a small (fractional horsepower) electric motor, and an electrical contactor with overload protection are examples of candidates for discardable modules. Electrical modules that are suitable for discard are often already designed that way, e.g., a 20-A circuit breaker or a 1-kVA constant voltage transformer. Electromechanical components can often be an integral part of the items with which they work, e.g., a sealed refrigeration compressor contains the motor, an electric drill contains its motor, and relays are often built into the item whose power they control. The mechanical aspects of motors and generators must be placed where they are needed (by function) rather than by any other type of partitioning. Par. 10-5, "Level of Repair Analysis", lists some of the models that are used to evaluate proposed designs.

3. *Similar-Part Partitioning*. Motors and generators would rarely, if ever, be partitioned this way because the mechanical part of the item must be where the item that produces or consumes the energy is. Items such as relays can be placed together where it is most convenient to service them, but that placement would rarely, if ever, facilitate their discardability.

4. *Reliability Partitioning*. If the goals of reliability partitioning and similar-part partitioning were to coincide, reliability partitioning might be useful in a design for discard program. It would be unwise to use this method for dissimilar parts because of the considerable uncertainty in predicting their average wear-out lives and because of the wide scatter in individual lives about that average. The transfer-of-mechanical-energy aspects of electromechanical items, such as motors and generators, are difficult, at best, to partition by anything but function; thus reliability partitioning for them is rarely, if ever, feasible.

5. *Cost Partitioning*. Cost partitioning can be effective as long as reliability, performance, and other important attributes are not degraded. For example, motors and generators would rarely, if ever, be partitioned this way. An expensive device in an otherwise inexpensive module, however, might be made removable so that when the revised module fails, the expensive device could be salvaged and used again.

6. *Testability Partitioning*. Testability partitioning can be useful as long as reliability, performance, and other important attributes are not degraded. If combining items with similar testability into a single module would improve the testability of those items, that aggregation could be helpful for discardability. Similarly, removing some items from a module that interfered with testability of the remaining items could also be helpful.

6-10.4 HYDRAULICS AND PNEUMATICS

Hydraulic and pneumatic technologies exist mainly because of their ability to transfer fluid energy over long distances easily and inexpensively, compared to mechanical energy. Only those types of partitioning that preserve the ability to convert the fluid energy back to mechanical energy reliably are desirable. The flexibility allowed by use of fluid energy can be a major factor in designing parts of systems for discard.

1. *Spatial Partitioning*. A storage tank for fluids is often located where there is adequate space, regardless of the length of fluid lines to and from the tank. Spatial partitioning would rarely be used for the pumps, motors, and valves of hydraulic and pneumatic systems because their positioning is determined by their function. Such partitioning might coincidentally be a result of some other type of partitioning that was instituted because of discardability.

2. *Functional Partitioning*. Functional partitioning is a very reasonable method to use in designing hydraulic and pneumatic items for discard, largely because function is the reason for using such items. In fact, for the mechanical aspects of such items, function is the only reason for putting them where they are. Any type of partitioning is not feasible if it interferes with the mechanical and functional aspects of

hydraulic and pneumatic items. Small pumps and motors are candidates for discardable modules, and it might be feasible to include the immediately associated gages, valves, and controls in such modules. Because fluid components are rarely used as ends in themselves, they can be an integral part of what they work with. For example, a hydraulically powered wheel can use the motor as an integral part of the assembly, and an air drill contains its motor. If economy and simplicity are derived from such modularization, it should be considered in a design for discard program.

3. *Similar-Part Partitioning*. This method would rarely be used in a design for discard program unless it was a result of some other desirable partitioning method. An example of its potential use is the combining of many similar fluid valves (controls) into one physical body that would be replaced as a unit. The decreased commonality of such partitioning would tend, however, to militate against its use, and if additional connectors were required, reliability would be decreased. Those devices with a mechanical function must be placed where that mechanical function is needed; thus similar-part partitioning will be very difficult for those devices.

4. *Reliability Partitioning*. When the goals of reliability partitioning and similar-part partitioning coincide, reliability partitioning might be useful in a design for discard program. It would be unwise to use it for quite dissimilar parts because of the considerable uncertainty in predicting their average wear-out lives and the large scatter of individual lives from the average life.

5. *Cost Partitioning*. Cost partitioning could be effective as long as reliability, performance, and other important attributes are not degraded. For example, fluid motors would rarely, if ever, be partitioned this way. An expensive device in an otherwise inexpensive module, however, might be made removable so that when the revised module fails, the expensive device could be salvaged and used again.

6. *Testability Partitioning*. Testability partitioning can be useful as long as reliability, function, and other important attributes are not degraded. If combining items with similar testability into a single module would improve the testability of those items, that aggregation could be helpful for discardability. Similarly, removing some items from a module that interfered with testability of the remaining items could also be helpful. If this partitioning requires extra connectors, however, the system reliability could be impaired.

6-10.5 OPTICAL AND ELECTRO-OPTICAL

Lens system devices represent a rather mature technology; making lenses and incorporating them into instruments are centuries old. Thus designers can concentrate on requirements such as design for discard. Electro-optical devices for image intensification, thermal imaging, optical-fiber communication, and laser trackers and range finders use relatively new techniques, many of which are recently out of the research laboratory. Most of the research and development is being done in the commercial sector. Like other portions of the commercial sector, many of the products are designed for discard simply because such designs are better and cheaper from the point of view of the manufacturer. Often the customers and users agree with these decisions. It is feasible for the Army to use the technology and discardability thereof that the commercial sector provides.

1. *Spatial Partitioning*. Spatial partitioning would rarely be used in a design for discard program unless it was implied by some other desirable partitioning methods. Fiber optics allow optical signals to be transmitted rather easily over long distances and thus can reduce the desirability of spatial partitioning. The opposite of moving items to places in which they will easily fit can also occur, especially in optical magnifying instruments. For example, in binoculars the optical path is made more complicated by folding it so that the instrument is more compact. Lasers produce invisible infrared radiation so that suitable safety measures (which are necessary as part of, or because of, the spatial partitioning) must be provided, during both use and any kind of maintenance.

2. *Functional Partitioning*. Functional partitioning is very reasonable in designing optical items for discard. Much electro-optical equipment in ordinary use is made of independent components (common modules) that could be discarded. Due to the high cost of the end-equipment and its lack of maturity as a technology, it is unlikely that whole pieces of equipment would be discardable. As the discipline matures and technology advances, this situation will change appreciably.

3. *Similar-Part Partitioning*. Functional partitioning is necessary for most components, such as optical lenses, electro-optical sensors, and electro-optical displays. Rarely would similar-part partitioning be compatible with functional partitioning. Because of the rapid changes and improvements in electro-optical technology, the Army will generally use the technology, partitioning, and discardability that the commercial sector provides.

4. *Reliability Partitioning*. When the goals of reliability partitioning and other types of partitioning coincide, reliability partitioning might be useful in a design for discard program. It would be unwise, however, to use it for quite dissimilar parts because of the considerable uncertainty in predicting the average lives and the scatter of individual lives about their average life.

5. *Cost Partitioning*. Functional partitioning is necessary for most components, such as optical lenses, electro-optical sensors, and electro-optical displays. Simple cost partitioning would rarely be compatible with functional partitioning. Because of the rapid changes in technology and pricing, the Army will generally use the technology, partitioning, and discardability that the commercial sector provides.

6. *Testability Partitioning*. Functional partitioning is necessary for most components, such as optical lenses, electro-optical sensors, and electro-optical displays. Insofar as testability partitioning is compatible with functional partitioning, testability partitioning is desirable.

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CHAPTER 7
MATERIAL SELECTION

The position of material selection in designing for discard is addressed by considering those characteristics of materials whose importance and perspective are appreciably different from what they are in ordinary design. The economic factors considered are initial cost, disposal cost, and salvage value. The materials properties discussed are physical and related properties. The special factors included are the strategic value and the packaging, handling, shipping, and storage requirements. Repairability is irrelevant in a discardable module except during production.

7-1 INTRODUCTION

In principle, during the design and development process a designer considers all factors related to materials. In practice, however, the resources available to designers do not permit an equally close examination of all factors for all materials. New and revised materials and processing methods in metals, plastics, ceramics, and composites are being marketed at a rapid pace. Every manufacturing or design group needs at least one materials specialist who stays current with new materials that are better for the application as well as existing materials that still satisfy the requirements. The trade press (Appendix A provides a list of some trade journals.) and trade shows are important vehicles for keeping up-to-date on new materials and their properties as well as on processing methods that give improved properties to existing materials.

Some of the newer materials, e.g., engineered plastics and plastic composites, are better than older ones, e.g., traditional metals. The traditional metals, however, are evolving with improved properties and processing methods that allow, for example, the weight of a metal casting to be reduced and thus eliminate the need for plastic or other substitutes.

In principle, a designer is always designing for discard at some assembly level. For the commercial market, the impetus is usually lower costs and/or better properties without regard to repairability. In the military market, maintainability has been emphasized for years. With emphasis on design for discard, the level at which discard occurs can be improved. Now a designer should also be asking, "How can I choose materials and fabrication methods so that I can put more functions in a module and still have it discardable upon failure?" That is, "What can I do so that this module can be better but still not worth repairing?"

This chapter discusses a few selected topics whose importance is different from that in ordinary design or whose importance must be emphasized in military equipment.

7-2 STRATEGIC VALUE

The strategic value of a material is related to its being available within a reasonable time regardless of cost. The concept applies during wartime and in preparation for wartime. Examples of potentially strategic materials are

1. Alloying metals, e.g., chromium, vanadium, and cobalt
2. Noble metals, e.g., gold, platinum, and palladium
3. Tin
4. Natural rubber
5. Petroleum, as both a chemical and a fuel.

These materials can become scarce during wartime. The shortage can be local, such as in a particular theater of operations, or global. The material need not actually be scarce in order to have strategic value; the threat of such scarcity is enough for the classification.

Another category of strategic materials is those that have been processed into useful form, e.g., iron ore that has been processed into steel. This country has far less capacity for processing many of these raw materials than it used to have. We now depend on importing them from overseas. Thus, even though the raw materials are not strategic, the processed materials might have appreciable strategic value.

Designers should consider the strategic value of materials used in discardable components and discourage the use of strategic materials. Plastics, for example, use petroleum in their formulation, and petroleum supplies can be reduced very quickly, e.g., the 1974 oil shortages and burning oil fields during Desert Storm. Rugged steel—forgiving of physical and chemical abuse—often uses chromium. During peacetime it might not be economically feasible to salvage materials that have strategic value, but the designer should consider the feasibility of salvaging such materials. Metals are by far the easiest materials to salvage and reuse.

7-3 COST

This paragraph addresses the cost of raw materials. Costs in general are treated in par. 10-2. The ratio of "cost of raw materials" to "total cost of finished product" can range from over 90% (especially in situations in which the assembly and testing costs are very low, such as simple metal fabrication) to less than 10% (situations in which the assembly and testing costs are very high, such as specialized electro-optical equipment). The major cost elements for raw materials are

1. *Purchase Cost*. This is often the major part of the cost.

2. *Incoming Transportation*. The raw material must be shipped from the supplier to the user.

3. *Incoming Quality*. The cost of monitoring the supplier, including the cost of a receiving inspection, depends on the quality history of the supplier and the testability of the raw material. To that is added the cost of poor product caused by nonconforming material that enters the manufacturing process.

4. *Processing*. The cost of manufacturing methods by which raw material is turned into a product can depend greatly on the quality and reliability requirements for the product.

The ideal situation for design for discard is to have the total of the raw material cost elements less than for repairable items. This is especially true in the early phases of design where cost models and their parameters are very approximate.

7-4 REPAIRABILITY

Once an item has been designed to be discarded rather than repaired, by definition, its repairability is irrelevant. Thus, although materials that cannot be properly repaired are not used in a repairable item, they can be used in discardable items. For example, some repaired plastics and cast metals are not very reliable; thus such materials would not ordinarily be used for a chassis or housing for a repairable item.

The item must, however, be readily replaceable, i.e., the assembly of which it is a part must be readily repairable. If maintainability programs are invoked improperly, they can be incompatible with a design for discard program. Even though an item is not repairable, it must be testable to determine whether it should be replaced or not.

7-5 DISPOSAL COST AND SALVAGE VALUE

This paragraph considers discarding items during noncombat situations. The disposal cost includes all costs that the Army incurs to discard an item so that it does not threaten the safety of people or the environment. The salvage value represents any reduction of the disposal cost realized when someone pays the Army for the items being discarded.

All equipment is eventually discarded because it is not worth repairing or it is obsolete. Three common types of discard are

1. The Army pays someone to dispose of the materials safely and properly for protection of personnel and the environment. The Army may also incur some of those expenses by using internal preparation facilities. Examples are modules that contain radioactive material, dangerous chemicals, or explosives.

2. Someone pays the Army for the items because the materials in those items can be salvaged at a profit. Examples are the recovery of lead from storage batteries and the recovery of gold from electronic connectors.

3. The Army pays someone to recover materials that are not otherwise valuable, but that have strategic value.

Disposal costs can become the determining factor in design for discard. For example, a carburetor which could be rebuilt 5-10 times, might be analyzed for replacement with a discardable carburetor which costs the same as parts and labor to repair the malfunctioning original carburetor. However, the cost to dispose of a few small repair parts (e.g., gaskets, nozzles) would be much less than the disposal cost of an entire carburetor; thus the total disposal cost of the discardable carburetor over the life of the original carburetor could be 5-10 times the disposal cost of the original carburetor and its discarded parts.

If a component contains hazardous materials, there could be a similar disposal-cost consideration if the normal partitioning methods did not isolate the hazardous material for separate disposal. Such cost differences could be severe and thus must be foreseen and included in the design for discard analyses.

7-6 PHYSICAL CHARACTERISTICS

Corrosion, fatigue, and wear are the major classes of failure for nonelectronic materials. These classes are not mutually exclusive, e.g., wear can be accelerated by corrosion. The cheaper that one tries to make a material, e.g., a "high-strength" steel, the more important it is to characterize the material in terms of its failure mechanisms. For example, "high-strength" steels often have only high tensile strength; their resistance to corrosion, fatigue, and/or impact can be low. That is, they are not as rugged (forgiving) as the traditional high alloy steels.

Corrosion is a major problem when components with electrical parts are stockpiled. When costs are driven down so that a component is discardable, the designer might use cheaper materials whose relative corrosion characteristics are not known or might not even be aware that substitute materials might cause corrosion trouble. For example, a plastic material that is noncorrodible might give off vapors that accelerate corrosion of other materials.

In principle, the problems of compatibility are not different in design for discard than in ordinary design. In design for discard, however, the designer might be using nontraditional materials that have nontraditional compatibility problems. Such compatibility problems can arise with

1. *Corrosion*. A material generates a corrosive atmosphere or is susceptible to corrosive products given off by other materials or provides places for corrosion to occur,

e.g., for moisture to collect, or is part of a chemical system in which corrosion occurs.

2. *Differential Thermal Expansion*. If the thermal expansions of materials in intimate contact with each other do not match, thermal fatigue can occur as the temperature cycles up and down. Also substantial internal stresses can be generated by differential thermal expansion during manufacture.

3. *Joining*. The techniques used to join materials, e.g., soldering, brazing, welding, and adhesive bonding, can create problems with thermal expansion, can be part of a corrosion problem, can reduce the strength of a joined material, or can have failure mechanisms of their own.

4. *Sealing*. Sealing an item to keep the outside environment out should be considered. Unfortunately, sealing can also keep the inside environment in, and that inside environment may be harmful to the items to be protected.

7-7 PACKAGING, HANDLING, AND STORAGE REQUIREMENTS

In principle, the problems of packaging, handling, and storage are not different in design for discard from what they are in ordinary design, and the choice of materials is not affected differently. In design for discard, however, the designer might make errors of omission or commission such as those that follow:

1. He might use nontraditional materials or processes that have properties of which he is unaware and that will be weaker in some way than traditional materials or will cause an adverse environment.

2. He might wrongly assume that the item need not be rugged because it will not be repaired. For many items, handling, transportation, and storage are the among the most severe environments the item experiences.

It is possible that a discardable item may be more rugged than a repairable one because the discardable item does not have to be taken apart. If so, the packaging could be simpler, and the handling and storage requirements could be less stringent. If an item is to be sealed, the discussion and cautions in Point 4, "Sealing", in par. 7-6 apply.

7-8 APPLICATIONS AND IMPACTS

Examples are given for each of five categories: mechanical, electronics, electrical and electromechanical, hydraulics and pneumatics, and optical and electro-optical. It is rare for a usable system to be in only one of these categories. For example, all systems have components that serve a structural (mechanical) purpose, many systems contain electromechanical devices, most testing uses electronic or electrical devices, and all devices (except static structures) generate heat that must be removed to keep the temperature of the device low enough. Thus no example is a pure case of the category in which it appears. Examples are discussed under the headings: strategic value, cost, disposal cost and salvage value, physical characteristics, and packaging, handling, and storage requirements. Repairability is not discussed; see par. 7-4 for the reasons. No examples are given for headings that do not directly apply to the category.

7-8.1 MECHANICAL

It is reasonable to substitute newer, less expensive structural materials for older, more expensive ones and/or to design for the finite life of structures. This subparagraph emphasizes the dangers involved in doing so. In the 1960s, 1970s, and 1980s the automotive companies made mistakes in this area. A very gradual approach should be used with many pilot field tests. In the vernacular, "Make small mistakes!"

1. *Strategic Value*. Some steel alloying elements, such as chromium, have strategic value. Checklists of such alloys should be available to the designer and his materials advisor. Steels that use substitute alloys are often not as rugged as the traditional high-alloy steels.

2. *Cost*. There is little difference in materials cost between discardable and repairable components when the same materials are used in each. If cheaper materials are used because the components need not be repaired, e.g., cast iron (not readily weldable) rather than steel (readily weldable), there can be difficulties controlling the fabrication processes in the factory. Designers must be aware of the delicate nature of some "high-strength", low-alloy, low-cost steels; the high strength might apply only to a few failure mechanisms and not to those experienced by the component during manufacture or in the field, especially if some misuse may be necessary in wartime.

3. *Disposal Cost and Salvage Value*. Heavy steel items in which the steel is readily separable from the remainder of the item generally have scrap value. Vehicles and heavy guns are in this category.

4. *Physical Characteristics*. The low-cost aluminum engine in commercial vehicles circa 1970 were not commercially successful. There were many difficulties that were apparently not anticipated during design and development. Radical departures from traditional materials require long development and pilot testing periods; there are just too many things that can and will go wrong. Strength is not a one-dimensional characteristic; it has many, many facets.

5. *Packaging, Handling, and Storage Requirements*. There is little or no difference in this category between repairable and discardable items of the same materials. If, however, radical changes have been made in materials, the damage due to shock and vibration during shipping must be carefully considered. When designing for a finite life, more complex models must be used to reflect the narrow requirements.

7-8.2 ELECTRONICS

All electronic items are also mechanical items, and they must be treated as such with regard to their failure mechanisms. For example, the substrate of an integrated circuit can physically break due to mechanical stresses and strains.

1. *Strategic Value*. The basic raw materials used in electronic devices generally have little, if any, strategic value. The processed materials, however, are another matter entirely. Many of the processed materials* are no longer made in this country because they can be imported from overseas much more cheaply, e.g., large silicon wafers used to make integrated circuits should also have United States sources whenever feasible.

2. *Cost*. The basic raw materials used in electronic devices generally have little, if any, effect on the cost of the finished item. The industry in general is trying to switch from the remaining few expensive raw materials to less expensive ones.

3. *Disposal Cost and Salvage Value*. About the only materials used in electronics that have salvage value are the noble metals used to prevent corrosion. Because of the increasingly high cost of such materials and the intense cost competition in the industry, strong efforts are being made to reduce the amount of noble metals used in electronic parts. Thus newer discardable items are likely to have negligible salvage value. If such parts contain environmentally damaging materials, disposal costs can be high.

4. *Physical Characteristics*. As features get smaller on printed circuits and integrated circuits, the physical characteristics of the materials come under renewed scrutiny. Generally, the electronics designer has no control over these physical characteristics; the electronic parts are purchased as the same components whether the module is repairable or not. The lack of repairability in the field does not imply the same for the factory; an important element of low-cost, high-quality electronics manufacturing is the ability to test (and repair) quality into an assembly.

5. *Packaging, Handling, and Storage Requirements*. These requirements are generally not any more important for discardable items than for repairable ones. Thus they do not appreciably affect the choice of materials. Because discardable items can be sealed more tightly than repairable items, the materials choices might be more flexible for discardable items without decreasing shelf life.

7-8.3 ELECTRICAL AND ELECTROMECHANICAL

The main properties of concern are conductive, magnetic, and structural. The structural concerns are addressed in par. 7-8.1.

*Processed materials lie in between raw materials and components. For example, silicon wafers for the production of microcircuits require very specialized, expensive production facilities. Many manufacturers of microcircuits buy the silicon wafers as incoming raw material and from those wafers produce the microcircuits. The choice of terminology between the raw material and component is often subjective.

1. *Strategic Value*. The basic raw materials used in electrical and electromechanical devices generally have little, if any, strategic value. For those materials that might have strategic value, the quantity used in these devices is relatively small.

2. *Cost*. In general, material costs cannot be appreciably reduced by choosing different materials for the components themselves. The design of their enclosures is often governed by safety and fire codes; thus radical substitution of materials is not feasible.

The use of aluminum wire with permanent, airtight connections, e.g., welded, to reduce cost might be feasible in discardable items, even though other types of aluminum connections can be unreliable. It is unwise to dismiss the idea of aluminum as a conductor** in discardable items in an effort to reduce cost just because it was found wanting in domestic and commercial wiring. This problem of "aluminum wiring" illustrates the challenges that economical design for discard faces. Old conclusions do not necessarily apply to new conditions of use and new technologies.

3. *Disposal Cost and Salvage Value*. Copper, aluminum, and ferrous alloys are the major salvageable materials. It is possible that noble metals used in electrical contacts, e.g., relay contacts, would be salvageable. The economic feasibility of such salvage depends on market prices for the materials and the technology involved in the salvage operations.

4. *Physical Characteristics*. The physical characteristics of materials that can be used in these items are not generally affected by a module being discardable. A potential exception was the trial of a plastic gyroscope for a discardable item; unfortunately there were too many difficulties, and the project was dropped.

5. *Packaging, Handling, and Storage Requirements*. These requirements are generally not any more important for discardable items than for repairable ones. Thus they do not appreciably affect the choice of materials. Because discardable items can be sealed more tightly than repairable items, the materials choices might be more flexible for discardable items without decreasing shelf life.

7-8.4 HYDRAULICS AND PNEUMATICS

1. *Strategic Value*. The basic raw materials used in hydraulic and pneumatic devices generally have little, if any, strategic value. For those materials that might have strategic value, the quantity used is relatively small.

2. *Cost*. Specialty structures, such as valves, cylinders, and pumps, lend themselves to highly engineered materials, e.g., engineered plastics or intricately fabricated metals. Some component costs could be reduced by choice of appropriate materials and fabrication methods.

**For example, aluminum interconnects have always been used in integrated circuits, and aluminum wire is the major new conductor used in electric power transmission lines.

3. *Disposal Cost and Salvage Value.* The metals in the pumps, motors, and lines might be salvageable. The economic feasibility of such salvage depends on market prices for the materials, the quantities available, and the technology involved in the salvage operations.

4. *Physical Characteristics.* The requirements remain essentially the same for discardable items and repairable ones. Proper design for finite life would be very difficult because the materials and fabrication processes are neither that well-characterized nor -controlled. Competitive commercial practices are probably driving the designs to lower cost materials with equivalent or superior characteristics, regardless of their repairability.

5. *Packaging, Handling, and Storage Requirements.* These requirements are generally not any more important for discardable items than for repairable ones. Thus they do not appreciably affect the choice of materials.

7-8.5 OPTICAL AND ELECTRO-OPTICAL

1. *Strategic Value.* The basic raw materials (glass and plastics) used in optical and electro-optical devices generally have no strategic value. For those materials that might have strategic value, the quantity used is extremely small.

2. *Cost.* Materials are chosen largely on the basis of applicable commercial technology rather than specifically for a military application. For example, the lasers, light-emitting diodes (LEDs), laser drivers, and integrated circuits that are unique to this category are usually made from gallium arsenide (GaAs) rather than silicon. The GaAs technology is currently much more expensive than the silicon technology.

3. *Disposal Cost and Salvage Value.* Disposal costs would be relatively low because of the small volume and weight of the items and their lack of major safety hazards. The salvage value of these items would be negligible.

4. *Physical Characteristics.* The requirements remain essentially the same for discardable items as for repairable ones. Competitive commercial practices can drive the designs to lower cost materials with equivalent or superior characteristics, regardless of their repairability.

5. *Packaging, Handling, and Storage Requirements.* These requirements are generally not any more important for discardable items than for repairable ones. Thus they do not appreciably affect the choice of materials.

CHAPTER 8 FABRICATION

"Fabrication" is used in its general sense of manufacture, production, construction, and/or assembly. The choice of fabrication methods in designing for discard is treated by considering those elements of the fabrication process whose importance and perspective are appreciably different from what they are in ordinary design. The major emphasis is on the three aspects of producibility: design, production planning, and prototyping. Fabrication techniques are discussed briefly and the virtual irrelevance of repairability is explained. Hypothetical and real examples are given to illustrate the ideas.

8-1 INTRODUCTION

With regard to design for discard, design and production engineers need answers to two questions:

1. If the item is discardable, what design and fabrication methods can we use that we cannot otherwise use?
2. If the item has not yet been determined to be discardable, what production techniques can be used to make it discardable?

Fabrication is an extension of design, i.e., the fabrication methods are influenced and limited by the design itself. In many cases the design specifies, or at least implies, a particular fabrication method.

Some companies ensure a constructive relationship between design and production engineers by having each of them spend time in the other field. This cooperative effort enables the designers to make appropriate adjustments before unforeseen problems become irreversible errors. The name "concurrent engineering" has been given to the effort wherein engineers from various departments, such as design, manufacturing, purchasing, and product assurance, are given the incentives and resources to cooperate proactively over the life cycle of the product.

Even though this handbook nominally distinguishes between materials and fabrication, they are intertwined. For example, a powdered ferrous metal cannot be separated from the fabrication techniques that transform it into an automotive crankshaft sprocket. Processing and fabrication techniques are being invented that allow the use of otherwise unusable materials and vice versa.

8-2 PRODUCIBILITY

Producibility is essentially the ability to produce in an economic and timely manner a specific item that conforms to particular requirements. Producibility depends on the existence of an ongoing production system and is meaningful only in relation to a particular such system. In any given instance

1. There must be adequate machines, skilled people, and materials.
2. There must be a production plant that can use them.
3. They must all be at the same place at the same time.
4. There must be a social, political, and industrial environment that allows the system to function properly.

The three subparagraphs that follow discuss three stages of preparing for producibility, which are design, production planning, and prototyping. MIL-HDBK-727 (Ref. 1) uses these classifications and can provide more information about them.

8-2.1 DESIGN

The word "design" is used in many ways. For example, design can mean something as nebulous as the system concept, or it can mean something as specific as (a) detailed drawings on a threaded bolt that specify surface finish, type of hardness, and the degree of hardness or (b) requiring that a hole be punched in a piece of steel, the steel be through-hardened to 42 Rockwell C, and finally the hole be ball-sized with a specified interference.

The process of design begins with a set of formal performance requirements and ends with a good technical data package (TDP). Thus a design has several levels at which the set of formal performance requirements is resolved into a hierarchy of successively lower design levels by a process of engineering creativity interspersed with tradeoffs that involve engineering and management judgment. This process translates the performance requirements into fabrication requirements. At each design level management must decide how much departure from the "usual way"* is to be encouraged, allowed, or discouraged; the management decision affects the amount of design for discard that is actually done. At higher design levels the effect of design decisions on producibility tends to be much less direct and is ascertainable, if at all, only by someone with much experience. Conversely, at the lower design levels the effect of design decisions on producibility tends to be quite direct and relatively easy to ascertain.

The designer has many constraints in addition to the usual resource constraints of people, time, and money, e.g., the "-ilities" (reliability, availability, maintainability, testability, producibility, supportability, sustainability, etc.) and design for discard. Designers do not set out deliberately to

*In particular, the traditional requirements for repairability.

create a design that is difficult and/or expensive to produce. Rather they allocate their effort according to their view of the situation, in light of their experience, and to the tools available to create and detail the design.

Choosing a fabrication method is done partly by designers and partly by production engineers; the amount done by designers depends on the industry and on the way a particular company is organized. Sometimes the choice of materials implies a particular production method, e.g., choosing a powdered iron, copper-impregnated part greatly restricts the fabrication methods that can be used. Sometimes the machines at a particular plant cannot hold the best and latest tolerances; therefore, it is easy for a designer who is without good support from production engineering to specify unrealistic tolerances.

In design for discard innovation can be very important, so the production department must also have the design for discard goal. Otherwise, it is easy for production engineers to take a "We can't do that here." attitude rather than a "How can we do this in an economic and timely manner?" attitude. This cooperation between design and production engineers must be ongoing; it is not sufficient for production engineers to explain at design reviews what the designers have done wrong.

8-2.2 PRODUCTION PLANNING

No design or technical data package can be 100% complete. When a design is passed to the production engineers, they have to translate the design documents into a production process and then make many tradeoffs and engineering judgments about both general and detailed procedures. This is especially true if a design for discard program has been innovative.

It is usually very helpful if the design engineers can become staff support for the production engineers—a reverse of their positions during the design period. If the cooperation is close, problems that arise during production planning and affect the design can be worked out before there is major trouble. These transition problems will be minimized if the production engineers have worked with the design group all during the design so that there are a minimum of surprises. This approach is often referred to as concurrent engineering.

Production engineers generally like to use processes that are well-characterized and -controlled in their plant. That is the way to get high yield and high reliability in the short term. It is not, however, the way to get high yield and high reliability in the long term where newer processes must be used that are less well-characterized and -controlled. For example, a plant that traditionally fabricates metal parts very well might do rather poorly at first at molding composites. When a design is called for that includes nontraditional materials or processes, the production and design groups must plan and work together and should probably get outside help from someone who has already had the experience. The two groups must also be sure that management will commit the capital resources, people, and time to develop a competent production facility that will be ready when it is needed.

Farsighted design and production groups recognize where technology is headed and install pilot facilities that can be used on small projects for which the full capability of the technology is not needed. Thus on-line experience is gained in design and production for such technology and with negligible waste, i.e., the product need not be close to perfect (in design or production) to meet its requirements. Many older materials were very forgiving, i.e., their application and processing could be far from optimal and yet not be appreciably degraded. The newer engineering materials are, at this time, rarely as forgiving.

8-2.3 PROTOTYPING

Generally, neither materials nor processes are static. As soon as both seem to be reasonably well-characterized and -controlled, someone will try to make the product better and/or cheaper. The previous characterization and control are then no longer adequate. A design for discard program encourages innovation. The net result is that the engineering state of the art is virtually always being advanced.

Prototyping is the appropriate engineering response to such advances. The design and production engineers can make small mistakes, learn from them, and forge ahead. Prototyping is a short-term expense with long-term benefits. When time is extremely important, it is common, but dangerous, to skip the formal prototyping. One rarely if ever skips informal prototyping wherein several things are tried to see which works the best. The prototyping is done in very early production if it is not done before then.

Prototyping is not limited to design and production; it must encompass the remainder of the life cycle. The formal requirements must be able to change as experience with the prototype equipment is acquired and evaluated by the development group and the users. Then the formal requirements and the needs of the users in the field can remain close together as the design progresses. An important purpose of field experience on prototype equipment is to provide information for the closed loop corrective action system. Establishing this system is essentially Task 104* of MIL-STD-785 (Ref. 2). Such a system enables the design and production groups to act on the data they receive from the field.

8-3 FABRICATION TECHNIQUES

Three general classes of engineered materials are metals, polymers and composites, and ceramics. Some materials, such as reinforced plastics, cannot be separated from their

*"The purpose of Task 104 is to establish a closed loop failure reporting system, procedures for analysis of failures to determine cause, and documentation for recording corrective action taken."

fabrication techniques. For example, the strength properties of a fiber-reinforced thermoplastic strongly depend on the orientation and local concentration of the fibers. Thermoplastics are being engineered and improved because they are cheaper to fabricate than thermosets, such as the epoxies. New measurement techniques are being invented for thermoplastics so that the raw materials can be characterized on-line, and thus the molding process can be controlled to produce a more consistent molded part. Some newer metal alloys and ductile ceramics are similarly tied to their fabrication techniques, i.e., the material and fabrication technique are developed together and are virtually inseparable.

Joining techniques, or their avoidance, are an essential part of any fabrication process. If an item is being designed for discard, the joining process can often be simpler or avoided altogether. The avoidance of joining is an important concept wherein instead of making several parts that must be joined, those several parts are combined into one part. Thus joining is avoided. The fabrication technique of molding, regardless of the raw material, has been used over the past several decades to avoid joining.

If joining is unavoidable, e.g., several items must be put inside an enclosure, the design and fabrication can often be simplified in design for discard by resorting to a permanent joining technique, such as welding, rather than using precision mating surfaces and removable fasteners, such as nuts and bolts. The selection of fabrication techniques during design should be done in conjunction with production engineers who are willing and anxious to look for simpler techniques. The selection of final design and fabrication techniques is often an iterative process during design for discard wherein the joining method is progressively simplified by the designers repeatedly asking "If this method is adequate, why can't we use an even simpler method?"

8-4 REPAIRABILITY AND DURABILITY

Once an item has been designed to be discarded rather than repaired, by definition its repairability is irrelevant. Thus, although fabrication methods that lead to nonrepairability are not used for a repairable item, they can be used for discardable items. For example, a completely welded housing would not ordinarily be used for a chassis or housing of a repairable item.

The item must, however, be readily replaceable, i.e., the assembly of which it is a part must be readily repairable. If maintainability programs are invoked improperly, they can be incompatible with a design for discard program. Even though an item is not repairable, it must be testable to determine whether it should be replaced or not.

Durability is not as important in a discardable item since the concept often implies the number of times an item can be repaired before it must be scrapped, e.g., a diesel engine can be overhauled only a limited number of times. Insofar as durability can also imply a storage life requirement, e.g., for ammunition, that requirement obviously remains for the discardable item.

8-5 APPLICATIONS AND IMPACTS

After several decades of relatively slow progress in innovating materials and their fabrication techniques, the process has speeded up so much that examples are out-of-date almost before they are printed. Even small design and production groups should have at least one person whose job is to keep up with advances in materials and their fabrication techniques. A design for discard program without such a person or group will not be successful.

8-5.1 MECHANICAL

The trend toward molding a complicated part without joints—instead of, for example, stamping several parts that must be joined—is being countered by competitive innovation in the traditional fabrication techniques of casting, forging, and stamping. Such innovation is possible not only because of new machinery and process control techniques but also because of new formulations of older materials that can take advantage of such innovation.

A major simplification of mechanical parts occurs when an open-and-close joint is replaced by something simpler. An open-and-close joint usually involves precision mating surfaces, a gasket to keep things in and/or out, and threaded fasteners to hold the joint closed. The design, fabrication, and parts for such a joint are expensive. The first simplification occurs when, for example, the several parts are replaced by a single molded composite part that is self-hinged and self-sealing. The next simplification occurs when that single part is permanently joined, and the final simplification occurs when the joint is eliminated.

Structural-foam plastics are an example of using a single material to perform the functions of both skin and filler.

The mechanical aspects of many devices, e.g., pumps and motors, can be simplified by designing them as a single unit that is assembled in the factory rather than as several items that are assembled in the field. For example, a flexible coupling is usually required when two shafts are connected in the field; this requirement stems from the inability to align things accurately and permanently enough in the field. A flexible coupling, as with any connector, generally has lower reliability than a permanent, accurate connection. A very common example of such simplification is the sealed refrigeration unit that contains the electrical drive motor and the refrigeration pump in one mechanically sealed unit.

8-5.2 ELECTRONICS

Three advances in technology have, as a side effect, increased the complexity of items that may be considered discardable:

1. Larger scale integration of semiconductor circuits
2. Reduction of component costs so that more items.

can be directly soldered onto a discardable printed circuit board

3. Multilayer printed wiring boards that combine many previously separate boards, along with their necessary wiring and connectors, into one unit or that allow very complex circuitry with hundreds or even thousands of connections to be put onto one board.

An example of printed wiring board technology is an 18-layer unit that requires only 2500 machine-wrapped wires rather than the 10,000 wires in the units it replaces. Also the new unit is cheaper, more producible, and more reliable and has better performance. As in many commercial electronics situations, the motivation for innovation is not only the discardability but also the improvements that result in cost, performance, producibility, and reliability.

Connectors of all kinds tend to be expensive and unreliable. Thus there is considerable pressure to reduce the number of connectors used. Without such connectors, however, it is difficult, if not impossible, to repair an item and retain its reliability, so essentially that end-item becomes discardable.

Some cost-reducing technologies, such as surface mounting, allow components to be placed so close together that repair, even in the factory, is not feasible. Not only is repair infeasible, but also some kinds of testing are not even feasible. In addition to the characterization and control of product and process, the quality and reliability are almost always tested into electronic items (either by weeding out poor items from a population, e.g., environmental stress screening and 100% test and inspection, or by repairing a complex item). Thus a production method must provide for adequate testability during or at the end of the production process. In summary, testability of electronic items cannot be waived merely because the items are discardable. Testability is essential for producibility.

8-5.3 ELECTRICAL AND ELECTRO-MECHANICAL

There are virtually no new techniques being applied to design for discard of electrical or electromechanical items with regard to their electrical nature. The techniques that are used are for the mechanical nature of the items, e.g., many electromechanical hand tools are now essentially unrepairable, except for the power cord. This is due largely to the structural aspects of the design, not the electrical ones. Subpar. 8-5.1 discusses this aspect of the items. Most fractional and low horsepower ac motors are now designed and produced so that they are not worth repairing.

Double shielding on many electromechanical items has allowed or required the use of an insulating—usually a composite plastic—exterior structure. Such a structure can have fewer pieces and is cheaper than the previously traditional metal structure that required precise joining methods.

8-5.4 HYDRAULICS AND PNEUMATICS

There are virtually no new techniques being applied to design for discard of hydraulic or pneumatic items, with regard to their fluid nature. The techniques that are used are for the mechanical, structural nature of the items and their design. Subpar. 8-5.1, "Mechanical", addresses this aspect of the items, for example, a sealed refrigeration unit that combines a motor and a pump.

Improved bearings and rotating seals can increase the life of an item and thus make it feasible to discard it upon failure. This improvement occurs largely because of newer materials rather than because of fabrication techniques.

8-5.5 OPTICAL AND ELECTRO-OPTICAL

Attenuation problems must be considered in the detailed fabrication method. Optical and electro-optical devices often require complicated alignment procedures in order to function correctly and reliably. For example, in an optical-fiber communication system, the output light from the light-emitting diode (LED) must be efficiently coupled to the fiber. Optical connectors can wear and/or become contaminated after each insertion-removal sequence. While assembling the system, workers must be protected from the laser radiation, the components must be protected from surge currents and concentrated radiated heat, and process controls must be in place to eliminate any electrostatic damage (ESD).

Even apparently small repairs on many of these complex optical and electro-optical items can require a virtual rebuild, the cost of which can easily exceed the purchase price of the original product. Thus such items are inherently major candidates for design for discard.

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2. MIL-STD-785B, *Reliability Program for Systems and Equipment Development and Production*, 15 September 1980.

PART THREE
SYSTEM CONSIDERATIONS

Part Three discusses the interactions of the design for discard program with the rest of the system programs during the acquisition process. The interactions are divided into five traditional major areas. These areas are

1. The information flow and documentation for the design for discard program
2. The interface with reliability and maintainability (R&M) engineering
3. The interface with manpower and personnel integration (MANPRINT)
4. The effects on system support
5. The evaluation and comparison of alternative items.

The first area is similar for all specific programs that are part of a project. The remaining interactions are essentially the same as those required in any project, i.e., they must be done regardless of whether there is a design for discard program or not. Part four addresses some of the more pertinent program considerations for design for discard.

CHAPTER 9
INFORMATION FLOW AND DOCUMENTATION

The nature of the information and its flow needed to implement a design for discard program are discussed. The first four areas—schedule, functional responsibilities, patterns of information flow, and documentation responsibilities—are typical of any program. The last three areas—reports, level of detail, and audit trail—should be tailored specifically to the design for discard program as they are needed.

9-1 INTRODUCTION

As used here, the term "analytical efforts" involves all analytic nonhardware exercises, e.g., the preparation of program plans, specifications, and tradeoff analyses. A contractor can be required to perform any analytical effort merely by explicitly requiring in the statement of work that it be done or by invoking the program plan that contains it. The nominal result of an analytical effort is a report. A data item is a report that is identified in the contract as a data item and must be physically delivered to the Army; it is not the work needed to generate it. The Army can have access to the report resulting from a analytical effort without making that report a data item. The Army, however, might want proof that the analytical effort has been done. For some tasks the report is not the major result; the major result is increased knowledge for its preparers.

A design for discard program basically needs four kinds of information to function effectively. They are

1. The requirement that the design for discard program be implemented
2. A design for discard program plan
3. Documented results of tradeoff analysis identifying design for discard candidates
4. Reports that document design for discard decisions and show the progress in implementing the program plan.

The second and fourth items are the subject of this chapter. As is true for any such program, some data item reports are necessary, but they should be kept to a minimum. The two risks in the amount of required documentation that are to be balanced follow:

1. The documentation is so minimal that the contractor might not understand what is to be done and/or is not doing it satisfactorily.
2. The documentation is so extensive that the contractor and/or the Army are spending too much of their resources on the paperwork rather than on the implementation and execution of the actual design for discard effort.

The need of the Army for a design for discard program involves, among other things, the balancing of long-term vs short-term objectives. That is, some design for discard activities might result in higher short-term costs in order to reduce the totality of maintenance and support costs in the long term. Contractual requirements concerning a design for discard program must be stated very carefully in order to give the contractor as many incentives as the Army has to achieve the short-term and the long-term objectives.

9-2 SCHEDULE

This paragraph discusses the schedule in terms of planning the program and the enforcement of that plan.

9-2.1 PLANNING

As with other programs, such as reliability and maintainability (R&M) and safety, that are essential to a project, the design for discard program must be planned, implemented throughout the project, and monitored. The program plan should contain at least the following elements:

1. A description of what the design for discard program is and how it will be conducted

2. A brief description of the instructions to the design group with regard to design for discard and the method of disseminating such instructions

3. Reference to the guidelines that designers will use or a statement that such document(s) will be created, subject to approval by the appropriate authority. Such documents should refer to tradeoff techniques used with other project objectives.

4. Description of the management structure and any key personnel that will implement the design for discard program. Include interrelationships among the pertinent elements of the management structure; in particular, the relationships of the design, support, test, and production functions must be explained with regard to the design for discard program. A concurrent engineering, or similar, approach can help to ensure that all departments are aware of the design for discard program and that each department is proactively assisting the company fulfill the design for discard objectives.

5. Description of how design for discard relates to the total design and the level of authority and constraints on the design for discard program

6. Identification of analytic tradeoff techniques and/or models to be used in design for discard determinations

7. Identification of the major inputs needed that will impact the implementation of the design for discard program

8. The method to be used during design reviews to discuss and measure progress on the design for discard program. (This element of the program plan should receive extra attention because progress on design for discard will generally be difficult to measure. It should also receive extra attention when the design for discard program is relatively new.)

9. Brief descriptions of any familiarization approaches for design and production* engineers and for managers. Since the design for discard program is relatively new compared to disciplines such as reliability, maintainability, and system safety, familiarization with the concept might be necessary.

Design reviews should be scheduled frequently enough so that problems with and progress on the design for discard program can be evaluated and appropriate corrective action taken. Thus no new channels for information flow are required. There are two kinds of documentation:

1. Guidelines for designers

2. Engineering tradeoff analyses and results for specific items in which design for discard was considered. The analyses are discussed in Chapter 10, "Analysis and Decision Techniques".

Each kind of documentation should be available at the appropriate design review.

9-2.2 PROJECT ENFORCEMENT

It is very desirable that no new information flow paths or new monitoring and enforcement methods be set up; instead every effort should be made to integrate the design for discard enforcement activities with the usual project activities such as logistic support analysis. The first such activity is the review of the proposal and contract. An appropriate design for discard program plan should be required as part of the contractor's proposal. Design for discard should be important during source selection and evaluation activities. Subsequent enforcement activities are that the program plan and the guidelines for designers should be included in the first design review and subsequent design reviews as appropriate. Engineering tradeoff analyses and results for specific items should be included in all subsequent design reviews; that is, the design for discard effort should be evaluated throughout the design and redesign process. For example, the evaluation during a design review or equivalent procedure should continue through any initial production runs during which detailed designs or production techniques can be changed and through all engineering change proposals (ECPs).

9-3 FUNCTIONAL RESPONSIBILITIES

No new information paths are needed in the Army or in the contractor's organization to identify functional responsibilities. The existing information paths, if used, will be quite satisfactory for all design for discard program needs.

Within the Army, the people who prepare a solicitation must be aware of the design for discard program and the relative importance of design for discard compared to other important project considerations. Similarly, the people who represent the Army in the preproposal conferences and who evaluate proposals must be aware of the design for discard program and its relative importance. The engineers who are responsible for the Army design for discard program must properly inform the project manager and contract negotiators about the seriousness with which the Army regards the design for discard program and the short-term costs the Army is willing to incur in order to achieve its long-term objectives of reducing the total Army maintenance load. In the absence of clear, complete, and correct information, the design for discard program might not be considered properly during the contract negotiation process. Chapter 10, "Analysis and Decision Techniques", and Chapter 17, "Contractual Elements", discuss some of the details that must be considered in this process.

*The terms "manufacturing" and "production" are considered to imply the same things as far as this handbook is concerned. Some companies do distinguish between the two terms, especially as applied to engineers, but that distinction is not the same among companies.

Within the contractor's organization, the design group is responsible for the actual designing for discard. The design group needs the assistance and active cooperation of production engineers, support engineers, reliability and maintainability (R&M) engineers, integrated logistic support (ILS) engineers, and quality engineers. Basically the design for discard program information and requirements must follow the same administrative paths that other project requirements take. The main destination of this information is the head of the design engineering group. He must ensure that information about the design for discard program goes to the production and support groups so that they can actively cooperate in the program. The purchasing department must be aware of this program, as well as all others, so that they do not unintentionally subvert* it.

There are few, if any, activities that should not be aware of the design for discard program and requirements concerning it.

9-4 INFORMATION FLOW

There should not be a separate special advocacy group for the design for discard program. A reasonable location for an advocacy group is among those concerned about maintenance and support. Information about the design for discard program should flow through the same system** that causes other useful information to flow—both within the Army and from the Army to the contractors.

Within the contractor's organization, regardless of how large it is, there need not be a separate system that is concerned with the flow of information for the design for discard program. The design for discard information should flow through the same project channels through which other information flows. The main impediment to the flow of design for discard information is the intensity of the design engineering manager's belief in the program. He must understand the thrust of the program, be convinced that implementing it is worth time and effort, and then enforce the implementation with the educational and managerial tools at his disposal. Similar considerations apply to the flow of information to the production and support groups.

No special milestones should be created for the design for discard program; design for discard should be incorporated into other project activities and milestones, e.g., the design reviews.

9-5 DOCUMENTATION RESPONSIBILITIES

There is a wide divergence of opinion on how much separate deliverable documentation (data items) should be required to execute a design for discard program. These opinions range from no documentation being necessary or even desirable to appreciable and detailed documentation being essential. The answer depends on the current general policy of the Army, on the management procedures and customs of the specific Army command, on the specific contractor's capabilities and history, and on the desirable ratio for resources of the contractor and Army devoted to the deliverable documentation of the program rather than to the substance of the program.

There is a need to document the designs being analyzed and the results of those analyses. The design engineering group has the responsibility for those documents and reports. In fact, they do document, as part of their ordinary work, all major tradeoff analyses with respect to the design requirements, and the documented analyses should be available to the design review group. The decisions should be formally documented via logistic support analysis (LSA) and other reporting documents because they drive maintenance concepts, allocation, provisioning, personnel requirements, etc. Such reports also provide a corporate memory of useful information and lessons learned for the future. The intensity of the contractor's commitment to the design for discard program will be difficult to measure by means of any documentation.

9-6 REPORTS

A final report documenting design for discard activities should be prepared. At scheduled design reviews the design review groups should review the work and progress of the design group with regard to the design for discard program just as they do for many kinds of analyses and tradeoffs. Design for discard activities and decisions should be documented in the design review minutes.

9-7 LEVEL OF DOCUMENTATION DETAIL

The level of documentation detail should be sufficient to retain corporate and Army memory of what worked, what did not work, and why, i.e., it should be suitable for corrective action by design engineers and management working on future projects.

The project responsibilities are to fulfill the contractual requirements. The contract can require that there be a design for discard program, but such requirements must not conflict with explicit maintenance and support requirements. The important thing about design for discard is that the designers seriously consider designing an item with the intent that optimally the Army will discard rather than repair it. That seriousness, i.e., the intensity with which designers approach the design for discard problem, is difficult to measure.

The Department of Defense (DoD) formal reliability programs, from their inception in the mid 1950s until the early

*For example, based on their experience on nondesign for discard projects, the purchasing department might consider the portions of the purchase requests that could greatly affect the discardability of the materials being purchased as relatively unimportant.

**The system of management, cooperation, and enforcement

1980s, were generally regarded as numbers games. That is, the DoD required that specific reliability analyses be performed and that related reports be submitted, and the contractors fulfilled those requirements. But few people in the DoD or industry actually did anything about those reports—*except to ensure that the paper work was done.*

A similar emphasis on reports rather than on the designers' intensity could cause a similar fate for the design for discard program. Thus the level of documentation detail about the maintenance and support attributes of a project should stay as it is and not be increased because of the introduction of a design for discard program.

9-8 AUDIT TRAIL

Audit trails should be established by expanding those for other logistic support analysis activities. The audits should be part of the LSA audits and should concentrate on the adequacy of

1. Contractor initiative in providing innovative alternative designs
2. Reports to help contractors and the Army do better in the future.

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CHAPTER 10
ANALYSIS AND DECISION TECHNIQUES

The several categories of techniques and models for analyzing costs are explained. First, the kinds of costs that must be considered are listed. Then the three major pertinent categories of analysis, namely, front-end, tradeoff, and level of repair, are explained. Finally, a perspective is provided by briefly discussing long-term military goals and system requirements.

10-1 INTRODUCTION

Design for discard is a program intended to affect the way the Army uses its limited resources. It is part of the plan to reduce the people and money devoted to supporting each soldier in the field while maintaining the required levels of operational readiness. This concept is sometimes referred to as improving the "tooth-to-tail" ratio of the Army. Conceptual models of actual activities are analyzed to help the decision maker perceive the logical consequences of any decision; subpar. 2-2.4, "Realism of Models", provides a perspective on this process. It would be nice to have one all-encompassing model that included all pertinent factors along with the data to measure them under any reasonable conditions. However, such perfect models do not exist. Therefore, the analyst uses several models to investigate the implications of several courses of action.

This chapter classifies models as front-end, tradeoff, and level of repair; these are not mutually exclusive categories. The *front-end analysis* is done at the front, i.e., near the beginning, of a project and thus necessarily is quite general and approximate. A tradeoff analysis calculates the technical performance of a system in terms of the various technical characteristics of its elements and then manipulates various combinations of those elements and their characteristics to discover what happens to the technical performance of the system. The level of repair analysis calculates the cost of repairs when done at each maintenance level. Some of the models can integrate this information and indicate the least-cost maintenance level at which each task can be done, i.e., optimize the system.

10-2 COST ELEMENTS

The general cost elements for a part could include development, purchase, supply pipeline, test (at indication of failure), and disposal. If the part can be repaired, the additional cost elements for the repair parts and repair are purchase, supply pipeline(s), test and repair (at indication of failure), and test of the repaired part. In any level of repair analysis (LORA) or repair vs discard analysis, the cost elements being analyzed must be detailed explicitly.

The major potential cost elements can be classified as original parts, repair parts, manpower (how many people), personnel (what skills and skill levels), facilities, instructional material, test equipment, and repair tools. Each cost element is often treated as linear in the number of items, with a fixed cost and an incremental cost per unit. The relationship can be stepwise linear, i.e., when the number of units exceeds a certain quantity, another capital investment must be made to increase the facilities.

Examples of further breakdown of costs are

1. *Cost of Maintenance Facilities.* Development and acquisition, utility costs, maintenance, and upkeep
2. *Support Equipment.* The equipment itself (including development and maintenance), the facilities for the equipment, support for the equipment, documentation for the equipment, and transportation for everything
3. *Inventory.* The inventory items, transportation, storage space, length of the supply pipeline, the inventory data system, entry into and retention in the data system, and purchasing and supervisory personnel
4. *Maintenance and Supply Personnel.* Labor hours, training facilities, training personnel, training documentation, length of time such personnel remain in maintenance or supply, and supervisory and clerical personnel.

Important data related to costs are mean time between removals (This is not necessarily equal to mean time between failures.), fraction of removed items that are good, mean time to repair, yield of the repair process, and durability.

Other major costs during the life of a component are

1. *Stockpile.* The cost of a stockpile depends on the physical and chemical environment desired in the stockpile. Components must be checked at appropriate intervals, and nonconforming items must be discarded.
2. *Logistics.* The component type must be entered into the bookkeeping part of the supply system. Sufficient numbers of the component must be available to fill the distribution pipelines. A system must exist to dispose of the discarded components. All logistics involve administrative costs; keeping track of warranted components and exercising the warranty involve appreciable administrative time. Administrative time is incurred not only by administrative clerks but also by operators, repairmen, and supervisors. These costs can be very important and must be evaluated when applying a design for discard program.
3. *Testing.* Testing requires trained people and the tools they need; the purchase and support costs of the test equipment can be considerable. Both the component itself

and the system of which it is a part must be tested. Some share of the latter cost must be allocated to the component. Simpler testing with cheaper equipment and lower skill levels is always desirable.

4. *Replacement Rate.* The "function" of a component includes a minimum reliability and testability. A component is replaced because an operator or repairman decides to do so, regardless of whether it is actually defective or not. The cost of use is ordinarily not an absolute number; it is a rate, e.g., cost per mile or cost per hour of mission operation. Thus an item that costs twice as much but is replaced one-third as often as a base item is cheaper than the base item.

5. *Downtime.* When a component fails, system performance is usually degraded or stopped. During that period the soldiers who are using or depending on the system are not being supported properly. Although such cost can be difficult to calculate in money, it is important.

6. *Strategic Materials.* A component that uses materials that are not readily replaceable in the short term consumes a valuable resource that is not measured in money. The use of strategic materials should be avoided when it is feasible to do so. See par. 7-2 for a further discussion of strategic value.

7. *Training.* The total cost to train repair people to test, remove, handle, and replace the component can be considerable. Insofar as the component is an end-item, the cost of training people to use it must be included in an overall cost. The most desirable design for discard does not adversely affect the costs to train repair people.

10-3 FRONT-END ANALYSIS

A front-end analysis is one that can be done very early in the project with only minimal data about the system. Many decisions are made very early that greatly affect the direction of the project, and by necessity they are made with very incomplete data. The "Palman Repair versus Discard Model", described in Table 10-1, is an analysis program that can be used at the front end of a project to determine design for discard potential.

An important application of a design for discard program is to find the drivers—the few concepts and/or items that determine some system parameters—for the system life cycle cost, manpower, and personnel. When using such models, it is essential to run sensitivity analyses for as many assumptions and input data as feasible. The sensitivity analysis allows the analyst to learn which assumptions are most critical to the predictions from the model. Then more attention must be paid to the validity of those critical assumptions, and less attention can be paid to those whose exact value is not very important.

10-4 TRADEOFF ANALYSES

Tradeoff analyses basically compare the effect on a system or equipment of making changes in various system or equipment parameters. For example, the modeled effect on system availability could be calculated for changes in the maintenance concept, or changes in some measure of operational readiness could be calculated for changes in system reliability. These analyses are most important during the concept exploration and definition and the demonstration and validation phases when many of the system and project decisions are being made. Virtually any equation or system model or project model can be used for tradeoff analyses.

Many logistic support analysis techniques from AMC-P 700-4 (Ref. 1) can be used to analyze various types of tradeoffs. Two important techniques, "Army Hardware versus Manpower Comparability Analysis", which is described in Table 10-2, and "Early Compatibility Analysis", which is described in Table 10-3, are recommended for manpower and personnel integration (MANPRINT) in materiel acquisition process evaluations. Early comparability analysis (ECA), which is described in Table 10-3, is also recommended as a useful Army tool to use before a contract is awarded.

10-5 LEVEL OF REPAIR ANALYSIS

Level of repair analysis is a technique and/or methodology used to establish the maintenance level at which an item

TABLE 10-1. PALMAN REPAIR VERSUS DISCARD MODEL (PALMAN) (Ref. 1)

PURPOSE

"To evaluate the breakeven purchase cost for an assembly between a repair and discard concept."

DESCRIPTION

"The PALMAN model calculates a breakeven cost based on various input variables over a range of expected deployment densities. If the actual (or expected) cost of procuring an assembly exceeds the model output the assembly should be repaired; if less, the assembly should be discarded. Although the PALMAN model was designed for a single maintenance level, adjusting variable inputs can reflect a Direct Support, General Support, or Depot maintenance location. There is also an expanded section covering initial provisioning costs. There are three general limitations to the applicability of the model: (1) the model only allows one maintenance level; (2) no subassembly repair is allowed (i.e., all parts removed to repair the main assembly are considered nonrepairable items); and, (3) the model assumes only one Depot. These limitations only restrict the model's use and do not make it unacceptable for repair versus discard analysis, especially in the earlier stages."

TABLE 10-2. ARMY HARDWARE VERSUS MANPOWER COMPARABILITY ANALYSIS METHODOLOGY (HARDMAN) (Ref. 1)

PURPOSE

"To estimate the manpower, personnel pipeline, and institutional training requirements of proposed materiel system concepts prior to Milestone I and thereafter."

DESCRIPTION

"The estimates are used to evaluate the Manpower, Personnel, and Training (MPT) impact of system concepts and to determine how concepts may be altered to save requirements. The estimates feed program documents (e.g., Qualitative and Quantitative Personnel Requirements Information (QQPRI), or Cost and Operational Effectiveness Analysis (COEA)) and may be used at Army System Acquisition Review Council (ASARC) reviews.

"Components from the current inventory are selected to represent components on the conceptualized system. The selected components are the Baseline Comparison System (BCS). Task data from the BCS components are used to estimate the workload that will be required by the conceptualized system when fielded. The workload is used to estimate the quantity and types of direct manpower required and the number of personnel required in the personnel pipeline. Institutional training requirements are estimated based on training required by the BCS components.Thus a set of BCS MPT requirements data is generated. Another set of data, the proposed system, is also generated. For this set of data, the BCS is modified to represent new designs and known improvements in technology. Also included is a [n] MPT data set for the system that will be replaced by the new system. Comparison of the replaced system (predecessor) with the other data sets enables a determination as to how fielding the new system will affect MPT requirement levels."

TABLE 10-3. EARLY COMPARABILITY ANALYSIS (ECA) (Ref. 1)

PURPOSE

"To identify the tasks which are costly in manpower, personnel, and training (MPT) resources (high drivers) in predecessor or reference systems most comparable to the system under development."

DESCRIPTION

"There are three interlocking objectives for ECA: (1) the establishment of soldier tasks as a common language for system design; (2) the identification of predecessor system tasks and potential new system tasks that are costly in MPT resources (high drivers); and, (3) the limitations of high drivers in contracted design by addressing MPT in planning, requirements, and contractual documents. The ECA technique is a 12 step manual process. The 12 manual steps of the ECA methodology are: (1) Determine if an ECA is appropriate; (2) Identify relevant MOSs [military occupational specialties] that operate, maintain, and repair the predecessor/reference items selected for study in Step 1; (3) Collect complete task list by MOS and major component for the equipment under study; (4) Collect data on task criteria as it relates to each specific task; (5) Assign values for task criteria; (6) Calculate the ECA task score; (7) Identify high drivers; (8) Conduct task analysis; (9) Conduct learning analysis; (10) Identify deficiencies; (11) Determine solutions; and, (12) Prepare report."

will be replaced, repaired, or discarded. LORA is explained in more detail in Ref. 2. Ultimately, the LORA results and outputs do the following:

1. Lead to the assignment of the maintenance portion of the Source, Maintenance, and Recoverability (SMR) Codes of AR 700-82 (Ref. 3). These codes assure uniformity and provide a means of interservice communication of information on multiservice equipment.

2. Provide a basis for development and assignment of maintenance tasks for a maintenance allocation chart (MAC), which aids in the organization of technical manuals

3. Provide data to the Logistic Support Analysis Record (LSAR) and the reliability, availability, and maintainability (RAM) programs, depending upon the life cycle phase in which the LORA is conducted

4. Influence and are influenced by the maintenance concept as part of the LSA process.

The three general classes of LORA models are for analyzing

1. *System and End-Item.* The two models that follow are the most popular and the most useful:

a. "Optimum Supply and Maintenance Model" described in Table 10-4

b. "Logistic Analysis Model" described in Table 10-5.

2. *Subsystem and Item.* See the system and end-item models in the preceding class.

3. *Specific Aspects of Repair.* Example models are

a. "Palman Repair versus Discard Model" described in Table 10-1

b. "Test Program Set—Cost-Effectiveness Evaluation Model".

In a design for discard program LORAs can be used in two ways:

TABLE 10-4. OPTIMUM SUPPLY AND MAINTENANCE MODEL (OSAMM) (Ref. 1)

PURPOSE

"To simultaneously optimize supply and maintenance policies while achieving a given operational availability target."

DESCRIPTION

"OSAMM determines at which echelon each maintenance function should be performed, or whether the maintenance function should be eliminated; (i.e., it does repair versus discard analysis as part of the LORA process). OSAMM incorporates the same supply algorithms as the SESAME model contains. These algorithms optimally allocate spares to achieve a required operational availability goal at minimum cost. In making the repair level decision, the model considers the spares, test equipment, and repairmen that will be needed to support the maintenance policy. Other costs such as transportation, cataloging, documentation, and Test Program Sets (TPS) are also considered.

"OSAMM considers three levels of indenture within an end-item: components; modules; and, piece parts. Failure rates are input by failure mode. Four echelons of maintenance are considered: Organizational; Direct Support Unit (DSU); General Support Unit (GSU); and, depot.

"OSAMM has three run modes. The first mode determines at which maintenance echelon repair should be performed given one method of repair. The second mode considers up to three methods of repair, determining the preferred method of repair and at what echelon repair should be performed. The third mode considers screening or Go/NoGo testing, which is used to verify that an item has indeed failed before it is sent back for repair or is discarded."

TABLE 10-5. LOGISTIC ANALYSIS MODEL (LOGAM) (Ref. 1)

PURPOSE

"To provide a tool for the evaluation of alternate support postures for Army equipment."

DESCRIPTION

"LOGAM is a deterministic model structured to perform logistics analyses in maintenance support situations where the emphasis is on the support channels required for a diversity of operating equipments. LOGAM can be used to evaluate alternate maintenance postures on the basis of LCC [life cycle cost]. Although operational and maintenance costs are emphasized, the model accounts for development and investment costs of prime and test equipment, spares, and facilities. In addition to the maintenance costs, LOGAM has the capability to evaluate theater O&M [operation and maintenance] costs from a TOE [table of organization and equipment]. TOE maintenance personnel costs can be evaluated from personnel data. Costs are printed at the theater level (case total) using both the LOGAM and DA PAM 11-4 format[s]. LOGAM maintenance analysis is based on a four tier support system (i.e., organization, direct support, general support, and depot).

"The test equipment and manpower demands are determined by the flow of materiel at a support echelon generated by the maintenance incident rate, mean time between maintenance actions, the on time fraction, scrap rate, false no go rate, and attrition. The maintenance demands and spares requirements at a support echelon are a result of the maintenance policy(s) used. LOGAM has 20 different maintenance policies to select from. The user can elect to choose any one of these policies or any combination of policies."

1. Items currently listed as repairable but whose LORA suggests that discarding is a feasible alternative can be scheduled for redesign as discardable items.
2. Alternative designs in new development or product improvement can be evaluated by LORAs until a reasonable design is evaluated as discardable.

10-6 LONG-TERM MILITARY GOALS

The long-term, broad goals generated by the combat developer are important and must be advanced by the design for discard process. A main element of the design for discard philosophy is a long-term commitment to improve the "tooth-to-tail" ratio of the Army, i.e., a larger fraction of the personnel and materials is dedicated to the battle because of the reduced support requirements. Too much emphasis on optimization for short-term results readily leads to neglect of long-term goals.

An example of long-term, broad goals is the AirLand Battle concept (Ref. 4). The AirLand Battle concept is based on securing the initiative and exploiting it vigorously. The basic tenets are initiative, agility, depth, and synchronization. Two important elements of AirLand Battle are

1. *Combat Resilience.* A weapon-system characteristic that permits an incapacitated weapon system to be restored quickly to some needed, useful, although possibly degraded, operational capability with the expedient resources available on the battlefield (Ref. 4)
2. *Battlefield Damage Assessment and Repair.*

A design for discard program could enhance these two elements of AirLand Battle by making repairs easier and less costly.

10-7 SYSTEM REQUIREMENTS

The system requirements for parameters such as performance, reliability, and maintainability are generally fixed. In discussions about the effect of design for discard on system or subsystem requirements, it is important to remember that a program is not allowed to degrade any requirements. The contractor would be able to make appropriate tradeoffs, e.g., between performance and reliability, within the system structure and components so that those requirements were not appreciably exceeded. The goal is to have the design for discard program reduce the initial and maintenance costs and improve the reliability, maintainability, and performance.

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3. AR 700-82, *Joint Regulation Governing the Use and Application of Uniform Source, Maintenance, and Recoverability Codes*, 8 November 1971.
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CHAPTER 11
INTERFACE WITH R&M ENGINEERING

The interface of reliability and maintainability (R&M) engineering and their associated tasks with design for discard is addressed in three main categories: reliability engineering, reliability-centered maintenance, and maintainability engineering. Three critical measures of reliability are discussed under reliability engineering: mission reliability, operational readiness, and sustainability. Even though testability is a subcategory of maintenance, its interface with design for discard is so important that it is treated separately.

11-1 INTRODUCTION

A design for discard program has a critical interface with reliability and maintainability (R&M) engineering because a design to increase discardability can affect the R&M of the system and its elements. Converting a repairable item to a discardable item has little effect on maintainability at the unit level of maintenance. Such maintenance is primarily test, remove, and replace, regardless of the discardability of the removed unit. A design for discard program can greatly affect reliability, but the system must still meet its reliability requirement. Testability and a design for discard program have an important interface because excellent testability at the unit level of maintenance is essential for cost-effective discardability.

Because a design for discard program is merely a part of a project, many project tradeoffs will be made that involve discardability and affect the R&M. Engineers must meet the R&M requirements of the system regardless of the existence of a design for discard program. Some of the following paragraphs explain the R&M concepts.

11-2 RELIABILITY ENGINEERING

Reliability engineering is that set of design, development, and manufacturing tasks by which reliability is achieved (Ref. 1). The existence of a design for discard program does not affect the importance of reliability engineering tasks; in particular, it does not decrease their importance. Tasks that involve the organization of knowledge about potential failures relate particularly to a design for discard program because items that need frequent repair or replacement are likely candidates for a design for discard program. Of all the reliability tasks in MIL-STD-785 (Ref. 2) that involve reliability engineering, the most common and helpful is Task 204, "Failure Modes, Effects, and Criticality Analysis (FMECA)".

Several useful concepts pertain to the ability of the soldier in the field to rely on the weapon systems. Three such concepts are mission reliability, operational readiness, and sustainability. The first is generally applied to a specific item; the other two generally refer to an Army unit.

11-2.1 MISSION RELIABILITY

Mission reliability is "The ability of an item to perform its required functions for the duration of a specified mission profile.". The mission profile is "A time-phased description of the events and environments an item experiences from initiation to completion of a specified mission, to include the criteria of mission success or critical failures." (Ref. 1). This concept is important for most items with reliability requirements.

An item to be used in several different places and for several kinds of missions could have a minimum mission reliability specified at each environmental extreme.

11-2.2 OPERATIONAL READINESS AND SUSTAINABILITY

"Operational readiness. The capability of a unit/formation, ship, weapon system, or equipment to perform the missions or functions for which it is organized or designed.

"Sustainability. The ability to maintain the necessary level and duration of combat activity to achieve national objectives. Sustainability is a function of providing and maintaining those levels of force, materiel, and consumables necessary to support a military effort." (Ref. 3)

Operational readiness and subsequent sustainability are among the most critical characteristics of any materiel that is required to support the soldier in the field. Without them, all missions fail. If the design for discard program degrades operational readiness and/or sustainability in any way, the analytic models used in the design for discard analysis are grossly inadequate. Savings produced in the logistic tail by the design for discard program could be used for the soldier in the field to improve operational readiness and/or sustainability.

An element of sustainability is combat resilience, which is related to battlefield damage assessment and repair (BDAR). Design for discard could expedite BDAR decisions because of reduced testing needs. Also the Army is in the process of formulating a design requirement for combat resilience (Ref. 4). As those requirements and programs are implemented, the models and programs used for level of repair analysis (LORA) will consider them. Such considerations will probably involve more complicated tradeoffs than now exist.

11-3 RELIABILITY-CENTERED MAINTENANCE

The intent of reliability-centered maintenance (RCM) is to reduce the amount and kind of preventive maintenance (PM) to what is essential and cost-effective to preserving the appropriate safety and reliability characteristics of the system. In principle, the interface between design for discard and the RCM philosophy and techniques is exactly the same as it is for repairable items; only the effects and outcome of RCM are different. RCM is a systematic approach to analyzing the item—system or equipment—reliability and safety information to

1. Determine the feasibility and desirability of PM tasks
2. Highlight maintenance problem areas for design review
3. Establish a cost-effective PM program for the item.

It is desirable to design any item to require as little PM as possible. When PM is necessary and done properly, it enhances the reliability and safety of the system. However, PM consumes Army resources, and there is always some risk that PM will be done improperly. Therefore, specifying PM involves tradeoffs, which is the rationale for RCM; discardable items can implement RCM better because their internal repair need not be considered. The existence of a design for discard program does not affect the importance of RCM; in particular, it does not decrease importance.

11-4 MAINTAINABILITY ENGINEERING

Maintainability engineering is that set of design, development, and manufacturing tasks by which maintainability is achieved (Ref. 1). The primary reference for maintainability engineering is MIL-STD-470 (Ref. 5). Maintainability of a discardable item is irrelevant except for testability, i.e., once an item is determined to be satisfactory or not, maintainability ceases to be relevant. One of the goals of the design for discard program is to improve maintainability when feasible. If there is an existing maintainability requirement, the design for discard program is prohibited from reducing maintainability below that requirement. The maintainability of the assembly where the discardable item is located may be affected. The elimination of a need for higher levels of maintenance can appreciably improve maintainability.

11-5 TESTABILITY ENGINEERING

Testability engineering is that set of design, development, and manufacturing tasks by which testability is achieved. Testability is "A design characteristic which allows the status (operable, inoperable, or degraded) of an item to be determined and the isolation of faults within the item to be performed in a timely manner." (Ref. 6). The several risks associated with testing can be classified as

1. The test can damage the item if done improperly or if the test equipment malfunctions.
2. A conforming item is declared nonconforming or to be among a group of suspect items (ambiguity groups).
3. A nonconforming item is declared conforming.
4. The group of suspect items is unreasonably large.
5. The test does not exercise the item under all environments (both internal and external) in the mission profile. This risk leads to Risk No. 3.
6. The fault is intermittent and does not show up in the test. This risk is related to Risk No. 5.

Because these risks are important but rarely known well, the LORA program should allow sensitivity analyses for these parameters. The risks are affected by the quality of the test equipment, the skills of the maintenance personnel, and the time available to do the job. Some items may have to be sent to a higher maintenance level where the magnitude of these risks can be much smaller. If the design for discard is done well, both the test equipment and testing skills will be reduced. In principle, the interface between design for discard and testability is exactly the same as it is for repairable items; only the effects and outcome of testability considerations and analysis are different.

Par. 5-2, "Testability", discusses these problems in more detail.

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CHAPTER 12 INTERFACE WITH MANPRINT

The interface of design for discard with manpower and personnel integration is explained in the following six domains: human factors engineering, manpower, personnel, training, health hazard assessment, and system safety.

12-1 INTRODUCTION

A design for discard program has a critical interface with manpower and personnel integration (MANPRINT) because a design to increase discardability can affect the manpower and personnel needed for the system and its elements. Converting a repairable item to a discardable item can have a significant effect on the manpower and personnel needed at higher levels of maintenance. The requirement for the MANPRINT program is in AR 70-1, *Systems Acquisition Policies and Procedures* (Ref. 1). AR 602-2, *Manpower and Personnel Integration*, (Ref. 2) is the basic regulation for the MANPRINT program.

MANPRINT is an umbrella concept used to integrate combat, training, and materiel development with personnel resources, capabilities, and constraints during all life cycle phases of materiel systems. It is to have equal priority with all other system characteristics. The program is concerned with six domains of activities: human factors engineering (HFE), manpower, personnel, training, health hazard assessment, and system safety. Each domain of activity is addressed in a separate paragraph with regard to the possible effects of a design for discard program. In principle, the interface between design for discard and MANPRINT philosophy and techniques is exactly the same regardless of the existence of a design for discard program; only the effects, e.g., changes in manpower and skills, might differ.

12-2 HUMAN FACTORS ENGINEERING

Human factors engineering is implemented by AR 602-1 (Ref. 3). The major source documents for this task are MIL-HDBK-759 (Ref. 4), MIL-STD-1472 (Ref. 5), and MIL-H-46855 (Ref. 6). The scope of human factors engineering, as described in AR 602-1, includes many of the areas identified in MANPRINT. The basic factors of the man machine interface, such as anthropometry, dexterity, and alertness, are the same regardless of the presence of a design for discard program, although some differences in skill specialties and reduced maintenance actions may exist.

In principle, the interface between design for discard and human factors engineering is exactly the same regardless of the existence of a design for discard program; only the effects might differ, e.g., the fact that portions of the item are nonrepairable is irrelevant to human factors.

12-3 MANPOWER

One of the major purposes of the design for discard program throughout the Army is to reduce appreciably the number of support personnel needed. The intended direct, short-term effect is to reduce the number of maintenance personnel at the direct support, general support, and depot maintenance levels.

The intended indirect, long-term effect is that reductions in maintenance personnel will reduce the number of people who support and train those maintenance personnel. That is, there is a ripple effect when the number of maintenance personnel is decreased. The amount of equipment and facilities used by the remaining maintenance personnel is decreased. Thus the need for maintenance personnel is reduced further. The need for maintenance personnel training is reduced, so the teachers, equipment, and facilities used in the schools are reduced. The need for manpower in the supply line and preparing maintenance manuals is reduced. The greatest savings come when a training institution can be eliminated entirely because there is no need for it and the overhead associated with that institution can disappear.

It is important, however, to understand and account for constraints that can exist on the size of maintenance crews or a training institution. For example,

1. The minimum size of a maintenance crew could be dictated by system safety considerations.
2. Manpower allocations could be subject to the needs of other programs, such as combat resilience, which emphasizes battlefield damage, assessment, and repair (BDAR), in which the wartime requirements can be different from the peacetime requirements. The Army has addressed BDAR in MIL-M-63003 (Ref. 7).

It is relatively easy to include the direct, short-term effects of discardability on manpower needs in the analytic level of repair analysis (LORA) models and associated computer programs. The ability to include and separately weight the indirect, long-term effects, intermediate-term transient effects, and any constraints on the size of maintenance crews should be built into those LORA models and computer programs.

12-4 PERSONNEL

A major purpose of the design for discard program throughout the Army is to reduce significantly the skill levels required of support personnel in the Army. For example, if the item is not to be repaired, there is no need to train people to repair it. The intended direct, short-term effect is to reduce the skill levels required of many maintenance personnel at the field and depot maintenance levels. Because much repair at the unit level of maintenance is remove and replace, the skill levels needed there will not change much.

If an item can be removed without testing, the skill level required at the field maintenance level will decrease, but if specialized testing is necessary before replacement (for discard), those skill levels might increase. What actually happens to the skill levels needed for testing depends on how many resources the Army devotes during development to improving testability.

The intended indirect, long-term effect is to reduce the number of highly skilled and trained people who train the maintenance personnel. The required minimum skill levels could also be affected by other programs, such as combat resilience.

12-5 TRAINING

Sometimes a new system is introduced to replace a repairable item; thus additional training at the depot level is required. If this system has discardable components, it decreases training requirements in the field. This reduction in training requirements results in simpler test equipment and less training for the people who maintain the test equipment, so the overall result is a large decrease in training.

As stated in par. 12-3, "Manpower", and par. 12-4, "Personnel", for the unit level of maintenance, the manpower and personnel will not be affected very much by a design for discard program. Therefore, the training resources needed for those people will remain about the same, although the specifics of training may be different. For the remaining levels of maintenance, the short-term and intermediate-term needs will remain about the same for two reasons:

1. It takes time for new-development items (including the changes due to a design for discard program) to reach the soldier in the field.
2. The transient effect when both discardable and repairable items are available for the same system might cause a slight increase in training needs simply because there are more types of items that must be included.

In the long term, over a period of several years, there can be a gradual decrease in both the numbers of people to be trained and the kinds of skills they must receive. This reduction will reduce the Army's need to compete with the private sector for the most skilled and highest aptitude people.

12-6 HEALTH HAZARD ASSESSMENT

In principle, the interface between design for discard and health hazard assessment is the same as it is for repairable items; only the effects and outcome of the assessment might be different. The amount and type of work done to assess health hazards will not change appreciably solely because of a design for discard program. There will always be new or revised materials and fabrication techniques on the market that can be used for making a device. Every portion of every item is disposed of sooner or later, so a design for discard program does not, by itself, introduce the problem of discard into Army procedures.

A design for discard program, however, can intensify the search for nontraditional materials, fabrication techniques, and disposal processes. Thus

1. During design, the Army might have to devote more resources to health hazard assessment than in the past. For example, if more types of items are discarded from the purview of the Army at the unit level, the resources used during design to analyze health hazards will have to be increased.
2. It is not possible to predict whether or not design for discard will reduce health hazards. For example, some alternative materials may introduce more health hazards than the original materials.

12-7 SYSTEM SAFETY

In principle, the interface between design for discard and system safety is the same as it is for repairable items; only the effects and outcome of the analyses might be different.

The amount and type of work done to assess system safety will not change appreciably solely because of a design for discard program. Insofar as there is less need to maintain individual components of the system and thus there is not as much handling of items, system safety can improve somewhat. Access to parts of the system will change for discardable items; this problem is discussed in Chapter 6.

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CHAPTER 13
EFFECTS ON SYSTEM SUPPORT

The effects of a design for discard program on system support are explained in terms of seven general categories as follows: the maintenance concept, integrated logistic support, logistic support analysis, inventory effects, replenishment of spares, maintenance training, and maintenance manuals.

13-1 INTRODUCTION

The main purpose of a design for discard program is to reduce the amount of Army resources devoted to system support, especially over the long term, and yet maintain the effectiveness of the weapon systems. For this to happen some tradeoffs are usually necessary among various measures of effectiveness such as life cycle cost (LCC) and combat resilience. A design for discard program that is not limited by short-term considerations will be useful regardless of the measure of effectiveness.

The maintenance concept is set early in the acquisition process; it should encourage discardability at the highest practical assembly level. The elements of logistic support must be analyzed and traded off with each other in order to achieve an optimum balance of system objectives and requirements. Several specific elements of system support, such as inventory size, replenishment of repair parts, maintenance training, and maintenance manuals, can interact significantly with a design for discard program.

13-2 MAINTENANCE CONCEPT

The maintenance concept is a general policy, rather than a rigid set of procedures, intended to constrain and guide the designers as they implement the formal requirements of the system. Maintenance has two missions:

1. The mission of peacetime maintenance is to maximize equipment readiness and service life.
2. The mission of battlefield maintenance is to help win the battle, and time is a major consideration.

The maintenance concept can be broken down into the following four major categories: the functional layout of the system for maintenance purposes, the equipment indenture levels at which malfunctions are tested and diagnosed, the philosophy of test and diagnosis, and the skill levels of maintenance personnel for test, diagnosis, isolation, and repair. Electronic systems tend to have quite different maintenance characteristics from mechanical systems.

Electronic systems tend to be difficult to diagnose and easy to fix—just replace the offending module—i.e., diagnostic methods are the driving factors in maintenance. The specifics of their maintenance tend to become fixed during engineering development, which is when the diagnostic details are planned.

Conversely, mechanical systems tend to be easy to diagnose and difficult to fix; thus their maintenance details tend to become fixed during engineering development, which is when the packaging details are planned.

13-2.1 FUNCTIONAL LAYOUT OF SYSTEM

The functional layout of a system greatly affects the maintenance concept, but maintenance is only one of many factors that affect the functional layout. A design for discard program emphasizes raising the hardware indenture level at which discard is feasible, e.g., (1) piece part to line-replaceable unit (LRU), (2) shop-replaceable unit (SRU) to LRU, or (3) LRU to end-item. This is an additional consideration in the functional layout that perhaps can provide more flexibility in planning the layout. Although the design for discard program does not affect the need to perform this activity, it can exert a strong influence on the outcome.

13-2.2 HARDWARE INDENTURE LEVEL

Because a design for discard program emphasizes raising the hardware indenture level at which discard is feasible, it significantly affects the hardware indenture level at which malfunctions are detected and to which malfunctions need to be isolated. Generally, a higher hardware indenture level for discard allows a higher hardware indenture level for detecting and isolating malfunctions.

13-2.3 MALFUNCTION DETECTION AND DIAGNOSIS

A design for discard program has a negligible effect on how malfunctions are detected, except for the effect due to the hardware indenture level at which the detection takes place. The design for discard program can, however, place more stringent requirements on the several kinds of inaccuracies in the diagnosis and isolation activities for the maintenance level at which discard actually occurs.

A design for discard program could have some effect on how decisions are made about the module to be replaced. At the unit maintenance level the hardware indenture level for module replacement would not be lower because much of the repair is by remove and replace. At higher maintenance levels, the decisions could be simpler because there probably would be fewer items at the lower hardware indenture levels.

13-2.4 MAINTENANCE SKILLS

A major purpose of the design for discard program is to reduce the number of maintenance people for whom high skill levels are required. The skill levels are shifted from lower hardware indenture levels to higher hardware indenture levels and from the ability to repair to the ability for minimum-error testing. There is a major interaction between the design for discard program and setting of maintenance skills.

13-3 INTEGRATED LOGISTIC SUPPORT (ILS)

Logistic support is the "Provision of adequate materiel and services to a military force to assure successful accomplishment of assigned missions." (Ref. 1).

Integrated logistic support (ILS) is "A disciplined approach to the activities necessary to: (a) cause support considerations to be integrated into system and equipment design, (b) develop support requirements that are consistently related to design and to each other, (c) acquire the required support, and (d) provide the required support during the operational phase at minimum cost.". (Ref. 2)

13-3.1 ELEMENTS OF ILS

The elements of ILS are*

1. *Design Influence*. This element is the relationship of the logistics-related design parameters of the system to its projected or actual readiness support resource requirements.

2. *Maintenance Planning*. This planning consists of the actions required to evolve and establish requirements and tasks to achieve, restore, and maintain the operational capability for the life of the materiel system.

3. *Manpower and Personnel*. This element involves the identification and acquisition of military and civilian personnel with the skills and grades required to operate and maintain a materiel system over its lifetime at peacetime and wartime rates.

4. *Supply Support*. Supply support encompasses all management actions, procedures, and techniques used to determine the requirements to acquire, catalog, receive, store, transfer, issue, and dispose of secondary items, provision for initial support and to determine the requirements to acquire, distribute, and replenish the inventory.

5. *Support Equipment and Test, Measurement, and Diagnostic Equipment*. This element includes all of the equipment required to perform the support functions except that which is an integral part of the materiel system.

6. *Training and Training Devices Support*. This element encompasses the processes, procedures, techniques, training devices, and equipment used to train personnel to operate and support a materiel system.

*See Appendix B of Ref. 3 for more detail.

7. *Technical Data*. These data include the scientific and/or technical information necessary to translate materiel system requirements into discrete engineering and logistic support documentation.

8. *Computer Resources Support*. This includes the facilities, hardware, software, documentation, manpower, and personnel needed to operate and support computer systems.

9. *Packaging, Handling, and Storage*. This element includes the resources and procedures to ensure that all system equipment and support items are preserved, packaged, packed, marked, handled, and stored properly for short- and long-term requirements.

10. *Transportation and Transportability*. This element includes planning and programming the details associated with movement of the system in its shipping configuration to the ultimate destination via the transportation modes and networks available and authorized for use. It further encompasses establishment of the critical engineering design parameters and constraints, such as width, length, height, and weight, that must be considered during system development.

11. *Facilities*. This element is composed of a variety of planning activities; all of which are directed toward ensuring that all required permanent or semipermanent operating and support facilities are available concurrently with fielding of the system.

12. *Standardization and Interoperability*. This element is needed to ensure that interservice; North Atlantic Treaty Organization (NATO) and American, British, Canadian, and Australian (ABCA) member countries; and other countries, standardization and interoperability potential is fully explored during system design.

All 12 elements of ILS must be developed in coordination with each other to acquire a system that is affordable, operable, supportable, sustainable, and transportable within the resources available. (Ref. 3)

13-3.2 EFFECTS OF DESIGN FOR DISCARD

A design for discard program is intended to affect all 12 elements of ILS as follows:

1. *Design Influence*. Design for discard is intended to reduce the readiness support requirements for the fielded system and in the long term for the Army as a whole.

2. *Maintenance Planning*. Design for discard is intended to eliminate some maintenance actions and to simplify some other maintenance actions. If there is a battlefield supply of the necessary repair parts, design for discard is generally considered to enhance combat capability.

3. *Manpower and Personnel*. Design for discard will eliminate some manpower throughout the logistic support chain. The supply pipeline, however, can be more complicated in the short term because of the presence of both the newly designed discardable parts and the older repairable parts that serve the same function. A similar difficulty

applies to personnel skills. This problem has to be addressed at a management level higher than that of individual projects. That is, the Army might increase the short-term cost of one project in order to decrease the long-term costs to the Army. These topics are discussed further in pars. 12-3 and 12-4.

4. *Supply Support*. Considerations similar to those for manpower and personnel also apply to supply support. Initial provisioning is impacted, and more spaces are needed to fill the pipeline. The supply pipeline is longer than the repair pipeline.

5. *Support Equipment and Test, Measurement, and Diagnostic Equipment*. Design for discard is intended to reduce the Army resources required overall for such equipment. At the maintenance level where discard is to occur, however, the complexity and cost of some of this equipment could be greater in a design for discard program. The reason is that a higher hardware indenture level is being discarded, and the risk of discarding erroneously must be correspondingly less. Conversely, at a higher hardware indenture level, fault isolation to lower levels is not needed; Go/NoGo testing at a higher level can be used. This simplifies support equipment design.

6. *Training and Training Devices*. Insofar as particular repair actions are eliminated, all the training and training devices associated with those actions* are eliminated in the long term. People must maintain the test equipment that is used on a system. As the test equipment becomes less complex, the training and training devices for it are reduced.

7. *Technical Data*. Considerations similar to those for training and training devices also apply to technical data.

8. *Computer Resources Support*. There are no special design for discard considerations for this ILS element, although the amount and complexity of computer resources support might decrease.

9. *Packaging, Handling, and Storage*. It is quite possible though not an immutable outcome of design for discard that the discardable item will be more rugged with respect to handling and storage than a repairable item. Design for discard could reduce packaging costs because repair parts for the discardable item are not needed and therefore not packaged. Also a sealed discardable item might require less packaging. Design for discard could reduce the number of items to be handled. Design for discard could also reduce the amount of storage and the number of items stored as well as the documentation required for storage.

10. *Transportation and Transportability*. Design for discard could enhance transportability by increasing the ruggedness of parts and decreasing the number of kinds of parts. Design for discard, however, is not likely to decrease overall transportation requirements appreciably.

*This statement is true for both the system being supported and the support system itself.

11. *Facilities*. The long-term intent of design for discard is to decrease appreciably the Army resources devoted to facilities by eliminating the functions of training, assembly, and/or repair that they housed.

12. *Standardization and Interoperability*. With design for discard the standardization and interoperability occur at a higher hardware indenture level. Thus they can be improved in the field by design for discard. During the acquisition phases more resources could be devoted to planning in this area to ensure the improvement. If those resources are used, these activities could be significantly enhanced.

13-4 LOGISTIC SUPPORT ANALYSIS (LSA)

LSA is "The selective application of scientific and engineering efforts undertaken during the acquisition process, as part of the system engineering and design process, to assist in complying with supportability and other ILS objectives." (Ref. 2). This definition shows the relationship between ILS and LSA.

An analogy for the relationship between ILS and LSA is that ILS ensures that everyone is playing from the same sheet of music and that the music includes the entire score, whereas LSA is writing the music.

The LSA program and its tasks and subtasks are explained in MIL-STD-1388 (Ref. 2). These tasks and subtasks should be tailored to each project. Although the outcome of these tasks can be appreciably affected by a design for discard program, the analyses are performed as usual. The major tasks that do not change under design for discard are

1. 100. Program planning and control
2. 200. Mission and support systems definition
3. 500. Supportability assessment.

The major tasks in which design for discard is important are

1. 300. Preparation and evaluation of alternatives. The purpose of this task is to develop an item that achieves the best balance among cost, schedule, performance, and supportability.

2. 400. Determination of logistic support resource requirements. The purpose of this task is to identify the logistic support resource requirements of the item in its operational environment(s) and develop plans for postproduction support.

13-5 INVENTORY EFFECTS

An intent of the design for discard program is to reduce inventories over the long term. That is, the number of items in the inventory probably will decrease, although the dollar value of the inventory could increase.

A short-term difficulty could occur when a repairable item is replaced by a discardable item. A reasonable approach is to handle the existing repairable items as if they were discardable and remove any existing piece parts from the inventory. The economic analysis should consider the usual short-term effects in a discard vs repair analysis and long-term effects, such as manpower and personnel.

If the repair parts have considerable commonality among many items, however, it is unlikely that they can be removed from the inventory until there is no longer any need for them. In the short to medium term (several years), this could be the major effect on inventories, i.e., a design for discard program would increase the inventories. Unless properly planned for and explained in advance, such an effect could damage the credibility of the design for discard program.

13-6 REPLENISHMENT

Replenishment of repair parts is a purchase of such parts after the initial purchase. It is quite common because

1. An initial purchase for the entire contemplated need is not feasible and/or not desirable.
2. A system or part is used by the Army for much longer periods of time than anticipated during the production runs.
3. Parts that have been lost, stolen, misplaced, misrouted, or washed out of the system must be replaced.

A technical data package (TDP) is necessary for any replenishment. If the item is already discardable, the TDP must be reviewed to ensure that discardability is a requirement. There would probably be little extra cost involved in the review and any needed upgrade, especially if the original TDP were prepared carefully.

If the item is a candidate for discardability, it is necessary to review the TDP to be sure that it can be discarded. The emphasis in a design for discard program is typically on form, fit, and function* rather than on the detailed internal design. Thus there might well be an extra cost to improve the procurement package, including the TDP, to ensure that the new, discardable items meet all of the original requirements for the item. This cost could be reduced by not having to describe piece parts or to repurchase discarded items. An example of such a requirement is the reliability under the current mission profile. The original TDP and current procurement package might rely on a fabrication specification to achieve the reliability because it had already been proven. If the internal design of the item is to be changed, the reliability should be demonstrated again. Extra time and money would be needed to support that process.

If the existing TDP is up-to-date and stresses form, fit, and function, the assembly can more readily be assimilated into a design for discard program. Unfortunately, the TDPs for some replenishment items are not kept up-to-date because of a lack of interest and/or resources by the cognizant command.

*Form, fit, and function are discussed in more detail in par. 2-3.

13-7 MAINTENANCE TRAINING

A major intent of a design for discard program is to reduce the amount of maintenance training by reducing the amount of maintenance that must be done on lower level assemblies and the complexity of test equipment. This reduction in turn reduces the number of people who must be trained. Both of these reductions will reduce the Army facilities, manpower, and personnel devoted to that training. Any such reduction also reduces the overhead personnel required in any organization. This overall reduction in resources will be a significant benefit of the design for discard program.

13-8 MAINTENANCE MANUALS

The design for discard program will affect the maintenance manuals only for the assemblies that are discardable. It will have a negligible effect on the maintenance manuals for higher level assemblies and for systems. Manuals that address the system and all of its elements individually can be smaller, simpler, and cheaper.

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CHAPTER 14
EVALUATION OF ALTERNATIVE ITEMS

The evaluation of alternative, competing items being considered for a specific function(s) is explained in terms of selection criteria, quality assurance, configuration control, and design reviews. All of these criteria and activities are the same for repairable items; only the emphasis and outcome differ.

14-1 INTRODUCTION

Alternative, competing items are the variety of items with the potential to fulfill the specified need and that merit formal investigation. The evaluation process for alternative items can begin with

1. Information extracted from an ongoing market surveillance
2. Nondevelopmental items (NDI) market investigation
3. The request for proposal (RFP).

The emphasis on design for discard should begin with the beginning of the evaluation process, which could include the conceptual studies that might, for example, include the goal of discardability for the entire item. As far as the offerors for an RFP are concerned, the Army states its emphasis in the weighting criteria for proposals. Those weighting criteria indicate how serious the Army is with regard to design for discard vs other project elements.

In the short term, the life cycle cost (LCC) of the item is probably the most important measure of effectiveness predicted. Unless some longer term, broader elements, e.g., explicit elements for training costs and overhead, that are not now in the life cycle cost models can be included in them, it will be difficult for the Army to mount an effective design for discard program. For the models available to use, the level of repair analysis (LORA) can show the relative costs to discard or repair an item at each maintenance level.

The quality assurance program and configuration control specifically related to the design for discard program are important once such a program has been included in the contract. Because the design for discard program is relatively new and is accompanied by other new programs such as combat resilience, the design reviews are important in order to ensure that the design for discard philosophy is being sufficiently emphasized by the contractor and the project monitors.

14-2 EVALUATION CRITERIA FOR SELECTION

This paragraph assumes that all items to be compared do satisfy the performance requirements. If an alternative item might perform better or worse than the original item, the differences between the two will have to be considered. This problem is not addressed here.

The most important criterion used to evaluate alternative items is minimum life cycle cost. Other criteria can include such diverse factors as quality of manpower, the availability of that quality of manpower, and reduction in maintenance workload. The main models used to evaluate these criteria with respect to design for discard are the LORA models.

14-2.1 LIFE CYCLE COST

Life cycle cost is the total cost to the Government to develop, acquire, operate, support, and, if applicable, dispose of the items. Life cycle cost is the most important criterion for comparing items, including those that are designed for discard, that meet the same Army requirements and goals. The main Army guidance documents for analyzing life cycle costs are Army Regulation (AR) 11-18 (Ref. 1) and Department of the Army (DA) Pamphlets 11-2 through 11-5 (Refs. 2-5). Life cycle costs are development cost, acquisition cost, support cost, and disposal cost (Ref. 6). The more traditional Army names for these categories are

1. *Research, Development, Test, and Evaluation (RDTE).* Typical RDTE costs involve planning, system management, research, engineering design, logistic support, design documentation, software, and test and evaluation.
2. *Investment.* Typical investment costs are related to production and construction and involve production management, industrial engineering and operations analysis, manufacturing, computer resources, construction, logistic support, supplier management, and quality control.
3. *Operating and Support (O&S).* Typical O&S costs involve system management; distribution; installation; operating personnel; operating facilities; property and real estate; utilities; operational data; maintenance management; maintenance personnel; repair parts and inventory; test and support equipment; maintenance facilities; training of operators and maintenance personnel including the real estate, buildings, facilities, and staff; maintenance data; transportation and handling; and modifications.
4. *Disposal.* Typical disposal costs involve management, product retirement, disposal of items that will not be repaired or have been condemned, and disposal of documents.

The process to consider life cycle cost for discardable items is exactly the same for nondiscardable items. The only difference is the outcome.

14-2.2 LEVEL OF REPAIR ANALYSIS (LORA)

The primary discussion of LORA is in par. 10-5, "Level of Repair Analysis (LORA)". LORA is the main method used to compare life cycle costs in a design for discard program. They are generally subsets of life cycle cost models that do not include sunk costs and other costs that remain constant among the alternatives. Ref. 7 on LORA and Ref. 8 on logistic support analysis (LSA) are important references for LORA.

The models should be able to discriminate among alternatives to those parameters of interest in the evaluation of design for discard candidates. Simulation with a wide variety and range of cases would show what could happen and thus ensure that the long-term Army goal for the design for discard program will be carried forward when engineers and technicians use those models to decide among alternatives. That long-term goal is to eliminate or reduce drastically the costs needed to sustain the maintenance and logistic support for a system. If the models being used are inadequate, the result is similar to the problem created when separate optimization of each of the subsystems of a particular system does not result in optimization of that system.

14-2.3 OTHER CRITERIA

All criteria implicitly presume that all minimum performance requirements will be met. Four additional criteria are briefly described:

1. *System Effectiveness*. For complex weapon systems simple measures of effectiveness such as reliability and maintainability are not adequate. The term "system effectiveness" was coined in the 1960s to permit a wide variety of measures of utility and satisfaction to the user. The principal early work on system effectiveness was the 1965 Weapon System Effectiveness Industry Advisory Committee (WSEIAC) model, which defined system effectiveness as the product of availability (Will it be working when it is needed?), capability (Can it "do the job" when it is working?), and dependability (Will it continue to "do the job" throughout the mission?). Since then, creating useful measures of system effectiveness has been seen as a major engineering and management task for each complex weapon system. Each weapon system office should have such models of system effectiveness of previous systems to use as a basis for modeling a proposed system.

2. *Short Acquisition Process*. When calendar time is vital, tradeoffs are made against cost and the original requirements. Preplanned product improvement (P3I) is used to bring the fielded item up to the original requirements.

3. *Exceed Minimum Requirements*. Sometimes the Army is willing to pay more for performance that exceeds the minimum requirements even though the life cycle cost is higher. Examples could be a tank that exceeds the minimum maneuverability and a projectile whose average lethality is higher than the minimum required. There are no specific references for this type of contracting; rather, management judgment by the Army is implemented via the usual contracting regulations.

4. *Unit Production Cost (UPC)*. Life cycle cost is discussed in subpar. 14-2.1, "Life Cycle Cost". Unit production cost (UPC) is an element of the investment phase of life cycle cost and has been emphasized by itself in Army procurement. UPC can be too narrow a criterion for design because it leaves out many other important elements of cost. It is useful to stress UPC in the early part of a project, e.g., during the concept exploration and definition and the demonstration and validation phases, because it connects the affordability of the system for the budget appropriators and because design engineers can easily overlook production costs.

14-3 QUALITY ASSURANCE

Quality is basically assured by the characterization and control of processes and products*. When alternative items are evaluated, the adequacy of their characterization and control is important. Acceptance inspection provides some additional assurance that the products conform to their requirements. The process of assuring quality for discardable items is exactly the same as for nondiscardable items; only the details are different (peculiar to the product), as they are for every product.

14-3.1 DURING PRODUCTION

Quality is assured during production by four activities: characterizing the product, characterizing the processes, controlling the product and processes, and auditing the product and processes. These activities are explained briefly in the paragraphs that follow:

1. *Characterizing a Product*. Before a process can be intelligently controlled, the important properties of the product being made by or affected by the process must be known. A product is characterized if all of its important properties are known and understood well enough to be measured and controlled. These important properties involve all of the parts of the product; they relate to the manufacture, storage, shipping, use, misuse, failure, repair, and disposal of the product, and to the people and environments associated with these activities. Users include those who operate the product, have their needs serviced by it, and maintain it.

2. *Characterizing a Process*. Characterizing a process consists of determining what to measure on the product, its

*As the concept of total quality has burgeoned circa 1990, the traditional concepts of quality control and quality assurance by inspection have expanded widely and rapidly. A few of the program names that DoD and industry are using to achieve total quality are total quality management (TQM), by the DoD; the Six-Sigma program, by Motorola; or parts per million (ppm) for fraction of defects, by the Army. This paragraph reflects the expansion.

parts, the equipment, the materials, and the environment; how, when, and where to measure; how to convert those measurements into knowledge about corrective action; what to change in the process or on the parts, how much to change it, and how to change it. A fully characterized process could be turned over to a computer program with appropriate sensors (input), controllers (output), and machines. Characterization of a process need only be adequate for the problems at hand; it need not be perfect. An example is a steel part whose length tolerance is a few thousandths of an inch. If the tolerance is changed to a few ten thousandths of an inch, it must be recharacterized for length measurements because temperature control is now critical. If the tolerance is changed to a few hundred thousandths of an inch, it would have to be recharacterized yet again.

3. *Control*. A product or process is being controlled if its characterization is adequate and is being applied. Being controlled is thus a matter of degree and is subject to engineering and management judgment, which always involves both short-term and long-term economic considerations. Adequate control is especially important for discardable items because access to the interior of such components and assemblies may not be possible after final assembly.

4. *Audit*. Audits are necessary in any process to ensure that management's original intent is being implemented properly. The traditional example of the need for audits is in banks and corporations, i.e., where money is the primary concern. People who are independent of the design and manufacturing groups are chosen to audit all the processes in all phases of a program. With design for discard such audits would include the usual procedures as well as auditing the conscientious and competent implementation of the program.

14-3.2 AT ACCEPTANCE

Quality assurance at acceptance is concerned with ensuring that there are no design or manufacturing deficiencies. Some characteristics require destructive inspection, e.g., for strength, or disassembly of the item to inspect the interior. Discardable items may be sealed to improve their life and performance and/or to decrease their cost so that nondestructive inspection of the interior, except through some electrical measurements, is impossible.

First article inspection determines whether the design, materials, and manufacturing methods can meet the requirements and generally uses relatively few samples. For many items lot-by-lot or item-by-item inspection is not destructive or difficult. Thus in these situations the methods of quality assurance at acceptance for discardable and nondiscardable items are not likely to be appreciably different.

Adequate economic inspection of some types of complex, discardable items (unlike the nondiscardable items that could have been used) will be infeasible because of their design and construction that allowed their discardability. In such cases the Army must rely on its ability and the ability of the manufacturer to characterize and control the item, its components, and the processes that specify and make them. Small arms ammunition, for example, is an area in which the Army has been practicing these techniques of characterization and control quite successfully.

14-4 CONFIGURATION CONTROL

Configuration control is the systematic proposal, justification, evaluation, coordination, approval or disapproval, and implementation of all approved changes in the configuration of a configuration item* after formal establishment of the baseline.

For discardable hardware configuration items developed at Government expense, the documentation shall describe form, fit, function, and testability. This documentation describes the physical and functional characteristics of the hardware configuration item as an entity but does not include characteristics of the elements that make up the hardware configuration item. The product configuration identification can consist of a detailed design specification that incorporates performance requirements.

Interface control is important for discardable items that are built according to form, fit, function, and testability requirements. MIL-STD-973 (Ref. 9) addresses the establishment of the interface control activity. For many devices, some as prosaic as a dc power supply, the interfaces are difficult to specify "properly"** because the interfacing needs have not been fully characterized. Interface problems other than form and fit are most likely to arise for transient rather than steady state conditions, and they can readily happen when new technology or new applications of existing technology are being used.

Another interface difficulty is that the interfacing specifications can depend on the exact nature of the design and construction of the discardable item. But such design and construction other than form, fit, function, and testability are not specified, nor is the configuration controlled for discardable items. The only recourse available under these circumstances is to define the function so that it includes all the interfacing requirements. Unfortunately, that complicates the design and manufacture of the discardable item and probably increases its cost and time for development.

Subpar. 2-2.3 discusses some of the limits for design for discard that can interact with configuration control in an

*A configuration item is an aggregation of hardware, firmware, or other computer software or any of their discrete portions that satisfies an end use function and is designated by the Government for separate configuration management. Any item required for logistic support and designated for separate procurement is a configuration item.

**By definition, if form, fit, function, and testability are specified "properly", there are no interface problems. The difficulty of course arises in having the depth and breadth of technical and application knowledge to specify some things "properly".

imperfect world, e.g., some of the psychological and cost barriers related to design for discard and the need for flexibility in the approach to design for discard.

14-5 DESIGN REVIEWS

Design reviews are covered by MIL-STD-1521 (Ref. 10). This paragraph emphasizes three of the occasions for design reviews and suggests ways to emphasize and review a design for discard program. The discussion does not include computer software configuration items because such items are not discardable in the sense of this handbook.

14-5.1 SYSTEM DESIGN REVIEW

The system design review (SDR) is conducted when the system characteristics are defined and the configuration items are identified. It should

1. Evaluate the optimization, correlation, completeness, and risks associated with the allocated technical requirements.
2. Review the system engineering process that produced the allocated technical requirements and the engineering planning for the next phase.
3. Review the basic manufacturing considerations and the plans for production engineering in subsequent phases.

This review is important because it must ensure that the design and production* engineers and managers

1. Are aware of the design for discard program and understand that its purpose is to encourage and allow the development and/or use of discardable parts
2. Are aware of all constraints on the design for discard program, such as a maximum cost of a discardable item
3. Are using appropriate tradeoff algorithms for life cycle cost and level of repair analysis and those algorithms include appropriate long-term considerations
4. Have appropriate parameter values to insert into the algorithms.

14-5.2 PRELIMINARY DESIGN REVIEW

The preliminary design review (PDR) is conducted for each group of configuration items to

1. Evaluate the progress, technical adequacy, and risk resolution (on a technical, cost, and schedule basis) of the design approach.
2. Determine its compatibility with performance and engineering specialty requirements of the hardware configuration item development specification.
3. Evaluate the degree of definition, and assess the technical risk associated with the manufacturing processes.
4. Establish the existence and compatibility of the physical and functional interfaces among the configuration item and other items of equipment, facilities, computer software, and personnel.

This review is important because it must ensure that the design and production engineers and managers

1. Are actively implementing the design for discard program and its philosophy
2. Are resolving any difficulties concerning constraints on the design for discard program, the tradeoff algorithms for life cycle cost and level of repair analysis, and parameter values for the algorithms.
3. Understand the difficulty of specifying interfaces and have taken appropriate action to ensure that the interface properties are part of the function specification.

14-5.3 CRITICAL DESIGN REVIEW

The critical design review (CDR) is conducted for each configuration item when the detail design is essentially complete. It should

1. Determine that the detail design satisfies the performance and engineering specialty requirements of the hardware configuration item development specifications.
2. Establish the detail design compatibility among the configuration item and other items of equipment, facilities, computer software, and personnel.
3. Assess configuration item risk areas on technical, cost, and schedule bases.
4. Assess the results of the producibility analyses of system hardware.
5. Review the preliminary hardware product specifications.

This review is important because it must ensure that the design and production engineers and managers

1. Have successfully implemented the design for discard program and its philosophy and that some concrete results were obtained
2. Have recognized and resolved any difficulties concerning constraints on the design for discard program, the tradeoff algorithms for life cycle cost and level of repair analysis, and parameter values for the algorithms.

14-5.4 OTHER REVIEWS AND AUDITS

Other reviews and audits mentioned in MIL-STD-1521 (Ref. 10) are system requirements review, test readiness review, functional configuration audit, physical configuration audit, formal qualification review, and production readiness review. Generally, the discardability of an item will not be an explicit part of any of these reviews, i.e., the scope and pace of the reviews should be the same, regardless of discardability.

Although design for discard is not an explicit part of the mentioned reviews and audits, it is still an important consideration that should be kept visible throughout the development cycle of the system or equipment in order to accomplish the design goals and requirements.

*In this handbook the terms "manufacturing" and "production" are considered to imply the same things. Some companies do distinguish between the two terms, especially as applied to engineers, but that distinction is not the same among companies.

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PART FOUR
PROGRAM CONSIDERATIONS

Much of Part Four is a reorganization of material in the first three parts so that it has a different perspective. Three primary program areas are considered in terms of their interaction with a design for discard program. Those areas are cost control, acquisition alternatives, and contractual elements. Chapter 15, "Cost Control", addresses costs in terms of design to cost and the way costs are affected by a design for discard program. Chapter 16, "Acquisition Alternatives", discusses product improvement, nondevelopmental items, and new development. Chapter 17, "Contractual Elements", includes only topics that could be appreciably affected by a design for discard program.

CHAPTER 15
COST CONTROL

The control of costs is explained in terms of design to cost (DTC), life cycle cost (LCC), and the producibility engineering and planning (PEP) program.

15-1 INTRODUCTION

The most common measure of cost is life cycle cost (LCC), viz, the total of costs from concept exploration and definition through disposal. Disposal costs are becoming more important as concern about the environmental impact of disposal increases. In particular, a design for discard program means that more material and larger units are being discarded and therefore that disposal costs could become a larger fraction of LCC.

The design to cost program is the primary means of providing cost control by defense contractors. The results of cost models used in various life cycle phases to estimate the feasibility and desirability of any design (discardable or not) determine how much discardability is implemented in a program. If the models predict a savings in LCC for any particular design over another equally effective design, the less expensive design should be used.

It is reasonable to hope for a decrease of 5-15% in life cycle cost effected by a design for discard program. This decrease would include related savings due to improved reliability and reduced support requirements.

15-2 DESIGN TO COST

Design to cost (DTC) is a general concept of managing LCC elements so that the contractor and Army are concerned about the cost of the project. The concept was developed as a cost measure that could be incorporated into a contract; it provides an incentive for cost control in current contract actions that would impact future life cycle phase costs. Ref. 1 is a comprehensive discussion of the Army DTC concept.

Design to life cycle cost (DTLCC) is the most general expression of DTC, but in practice it is difficult to use. A vigorous emphasis on design for discard can reduce the LCC by improving the tooth-to-tail ratio of the Army. DTLCC can be broken into elements such as design to acquisition cost and design to operating and support cost (DTOSC). Design to acquisition cost can be broken into several categories, which are not necessarily mutually exclusive, such as design to unit production cost (DTUPC) and flyaway cost. The emphasis in this handbook is on LCC because various and disparate elements of LCC must often be traded off in a design for discard program. For example, upgrading the reliability and testability of a system as part of the design for discard program, e.g., by built-in test, could result in increased up-front costs but should appreciably reduce operating and support cost by reducing the total workload and the resultant need for manpower, skills, test equipment, repair parts, and training resources.

15-3 LIFE CYCLE COST ESTIMATES

Life cycle cost estimates are intended to quantify all of the costs related to a system, usually in considerable detail; the concept is excellent, but accurate and useful implementation can be difficult. In particular, its accurate use with respect to design for discard has many pitfalls. Three examples of such dangers are

1. The actual disposal cost of a disposable element can be considerably different from the disposal cost estimated in the LCC model because both technical knowledge and social attitudes about materials and their disposal can change appreciably over the life of some materials.

2. The cost of the full logistic tail must be considered (This is analogous to zero-based budgeting.) for training of maintenance personnel. Examples of such costs that might not be included in an LCC model are the training facilities (buildings, grounds, and equipment) for instructors and for

students, personnel costs to train instructors, personnel transportation, support equipment, and overhead*.

3. The properties of many relatively new materials, e.g., engineered plastics, new metal alloys, especially their long-term behaviors, e.g., life, toxicity, creep, hermeticity, for use in discardable items are not known accurately enough at the design stage. Thus the designer makes engineering guesses about these properties.

Similar concerns about the general use of LCC models are given in pars. 4B3 and 4B4 of Ref. 1; those concerns apply especially to design for discard because the design for discard philosophy encourages designers to think in nontraditional ways about materials, components, and assembly methods. Descriptions of models accepted by the Army for logistic support analysis (LSA) are given in Ref. 2. Forty-seven of these apply at least in part to some category (operating and support, research and development, or investment) of LCC, and 12 apply fully to all three categories.

15-3.1 MODELS

A principal intent of a design for discard program is to reduce the intensity of maintenance training by reducing the amount of maintenance that must be done on lower level assemblies. This reduction in turn reduces the number of people who must be trained. In the long term both of these reductions will reduce the Army facilities, manpower, and personnel devoted to maintenance training. Such a reduction also reduces the overhead personnel required in any organization. Modeling this situation adequately is very difficult, and it is not clear that existing LCC analyses have yet reached that goal.

Many LCC models analyze only a portion of the LCC costs. Three types of LCC models are relevant to design for discard:

1. *Framework LCC Models*. They are partial LCC models that allow the user to put estimates into a structure that performs utilities such as documentation and updating of inflation and facilities. These models are useful and flexible but do little actual cost estimating.

2. *R&M-Based LCC Models*. They are partial LCC models that generate the operating and support (O&S) portion of their estimates based on reliability and maintainability (R&M) information input by the user. These models provide excellent insight into the design for discard costs if, and only if, good inputs are available.

3. *LORA Models*. They are partial LCC models that conceptually provide good information for use in more complete LCC models if the input is similar to that for the R&M-based models. If a LORA model does not adequately quantify design for discard training cost reductions or adequately capture the complexity of battlefield repair, it creates a bias toward fixing things in the field.

*Overhead costs must be explicitly broken out in zero-based budgeting and in exploring the full logistic tail.

Refs. 3-6 provide useful information on creating the models and obtaining data to evaluate them. Ref. 7 concentrates on the LORA models.

15-3.2 PARAMETERS OF THE MODELS

Most of the existing R&M-based LCC models require many inputs, and some of these inputs are difficult to obtain early in the life cycle of a system. Experienced users of these models have developed rules of thumb for use in the early life cycle. The novice user of most of the R&M-based models will have a difficult time developing inputs during the early life cycle.

For any engineering problem, including design for discard, it is much easier to generate a mathematical model than it is to obtain suitable empirical data to use in that model. This is especially true insofar as the design for discard program is concerned with reducing long-term costs, such as facilities costs and overhead costs for training. For example, the application of a design for discard program should reduce manpower requirements to maintain the item; this reduction would in turn reduce training cost. With fewer items being repaired the requirements for test equipment and the number of test program sets that have to be procured are reduced. On the other hand, replenishment repair part costs will be increased because more items will be discarded.

The project office must have appropriate data to use in-house for DTC procedures and for contractors to use in their tradeoffs, regardless of the phase in which the model is used. The data must be such that short-term gains are rejected when they do not advance the long-term Army objective of improving its tooth-to-tail ratio.

15-4 PRODUCIBILITY ENGINEERING AND PLANNING (PEP)

Producibility interacts actively with the design for discard program and should be emphasized during the design and development activities. The project office should encourage experimenting with newer production techniques, even though it incurs a short-term cost penalty. Such production trials should be done at first on noncritical components, i.e., components for which the production process for the new part being designed for discard is not pushed to its limits. Then when such a process is needed in order for an item to be discardable, the process is no longer experimental. The LCC models and/or their interpretation should be sufficiently flexible to allow this experimentation and development by the Army and/or its contractors.

To trade off effectively with regard to design and producibility, the project and contractual structures must provide sufficient incentives to ensure that design and production engineers do cooperate actively, e.g., in a proactive concurrent engineering approach. Design for discard cannot succeed on the desired scale for the Army without active cooperation, foresight, and interaction.

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CHAPTER 16
ACQUISITION ALTERNATIVES

The interactions of acquisition alternatives with a design for discard program are explained in terms of materiel improvement, nondevelopmental items, and new development.

16-1 INTRODUCTION

The alternative approaches for both major and nonmajor Army acquisition programs that follow are in order of preference:

1. Avoid the acquisition of materiel by changing tactical or strategic doctrine, improving training, or improving organization.
2. Improve an existing Army system through either preplanned product improvement (P3I) of the system or a new product improvement program (PIP).
3. Use nondevelopmental items (NDIs), in either the same environment for which they were designed or a different environment, in which case the hardware and/or operational software might need to be modified to accommodate the new environment.
4. Initiate a new development program. (Ref. 1)

This handbook is concerned only with Alternatives 2, 3, and 4. Design for discard is both desirable and tractable for Alternatives 2 and 4; discardability is a desirable characteristic of NDI (Alternative 3). Because choosing off-the-shelf components is an essential, common aspect of design, NDI does involve design work, and a design for discard program does apply directly.

All of the ordinary tasks that must be done during any acquisition must also be done when the acquisition involves a design for discard program. For example, life cycle cost (LCC) models and level of repair analysis (LORA) are essential tools in an acquisition, regardless of the presence of a design for discard program. There are three essential elements that distinguish a design for discard program and that must be provided:

1. *Awareness Training*. Engineers and managers must be aware of the importance of discardability at a high assembly level (hardware indenture level) as a product characteristic.
2. *Incentives for Initiative*. The product and project requirements must include provisions that encourage engineers and managers to take an aggressive initiative to raise the assembly level at which discard occurs.
3. *Adequate Analytic Tools*. The models (and parameters therein) that engineers use for LCC analysis, design tradeoffs, and LORA must reflect the long-term goals of the Army about discardability. Chapter 15, "Cost Control", describes several tools that allow appropriate tradeoffs of higher short-term costs for reduced long-term costs.

16-2 PRODUCT IMPROVEMENT OR REDESIGN

Existing materiel can be improved in three ways: an engineering change that reconfigures a type-classified item that is in production, an improvement that reconfigures a type-classified fielded item through a PIP, or an evolutionary P3I.

16-2.1 ENGINEERING CHANGE PROPOSAL (ECP)

This subparagraph is concerned with Class 1 engineering changes in which the change is necessary or it offers important benefits to the Government. ECPs can be necessary when choosing among acquisition alternatives for discardability because the products from the alternatives will not be always be alike. Two categories of such changes are improved logistic support requirements and lower life cycle cost.

An engineering change for an item could be initiated for the primary purpose of making that item cost-effectively discardable. Although some of the other characteristics of the item might also improve, e.g., cost, weight, and/or reliability, it is not necessary that they do so.

An engineering change for any other purpose should be investigated to see whether designing for discard can make the change more cost-effective. Value engineering can provide managers, engineers, and logisticians with a viable vehicle for incorporating design for discard concepts into production items. For the investigation to take place, however, the design for discard program must reach the engineers and managers involved with engineering changes. The presence of a design for discard program does not change anything else that traditionally must be considered and analyzed for an engineering change.

16-2.2 PRODUCT IMPROVEMENT PROGRAM (PIP)

A product improvement program (PIP) is any effort to improve the fielded inventory of a type-classified standard item and should include a design for discard program if at all appropriate. The design for discard program will be essentially the same, whether it is in a PIP, a new development item, etc. A PIP can originate as

1. A follow-on to an engineering change in an item that is in production

2. A response to user problems with the fielded system or to modifications required for a revised threat

3. A need to convert a particular repairable item to a discardable one.

Some of its purposes are significant improvements in LCC, reliability, durability, and maintenance.

16-3 NONDEVELOPMENTAL ITEMS

Because there is nominally no development effort associated with NDIs, the design engineers associated with the project do not do detailed design. Thus there is no Army- or contractor-initiated design for discard. Many companies in the commercial marketplace do develop many discardable products simply because people like their cost-effectiveness. They are, however, performing many design tasks, especially when existing components are brought together to make the desired system.

16-4 NEW DEVELOPMENT ITEMS

Development of new items is the least desirable acquisition alternative. When it is undertaken, it should, where feasible, integrate proven components or use evolutionary technology rather than use new revolutionary technology, regardless of the existence of a design for discard program. (Ref. 1)

16-4.1 SYSTEM INTEGRATION

System integration is the selection, combination, and coordination of existing components to provide a new capability. It is a combination of NDI and new development. Vehicles and the vehicular aspects of systems are often examples of system integration. Distinctions between NDI and system integration are a matter of degree.

Design for discard can be an important force in system integration projects by intentionally selecting cost-effective discardable items to use in the system. Some off-the-shelf components, i.e., NDI, for such systems are discardable solely because of market forces and technology opportunities.

16-4.2 ADVANCING THE STATE OF THE ART

All portions of a project that advance the state of the art must go through all phases of the acquisition process in order to provide a sure, cost-effective fulfillment of the requirements of the Army. The design for discard program, including the provision of adequate analytic tools, should be a part of all acquisition phases. It should begin in concept exploration and definition by identifying materials, technology, and manufacturing processes that are likely to stimulate and permit design for discard. In concept exploration and definition the awareness training and incentives for design for discard initiative are the most important. During demonstration and validation design for discard can become part of the detailed design process and of the producibility engineering and planning (PEP) program. In demonstration and validation the awareness training and incentives for initiative must continue, and detailed analytic tools must be provided. During engineering and manufacturing development the design for discard initiative should be part of any redesign in this phase and of the PEP program. In this phase the analytic tools and incentives for initiative are very important. During the subsequent phase the manufacturing aspects are dominant, but the analytic tools and incentives for initiative continue to be important.

REFERENCE

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CHAPTER 17
CONTRACTUAL ELEMENTS

This chapter summarizes the contractual elements that could be strongly influenced by a design for discard program. The elements discussed are criteria for source selection, statement of work, incentive clauses, specification requirements, inspection and acceptance, warranties, and second sourcing.

17-1 INTRODUCTION

Chapter 16, "Acquisition Alternatives", discusses the alternatives for acquisition. Par. 16-1, "Introduction", presents three essential ingredients—awareness training, incentives for initiative, and adequate analytic tools—for a design for discard program that would not otherwise be part of an acquisition. These three ingredients are the contractual elements that might be strongly affected by a design for discard program. All other contractual elements for a design for discard program are part of every acquisition, so they are not discussed explicitly in this chapter.

A vital factor in the effectiveness of any contract requirement is how strongly the contractor believes that the requirement will be given high priority by the Government when tradeoffs have to be made among schedule, cost, and other project requirements. Reliability requirements may not be met if there is a lack of such high priority.

17-2 CRITERIA FOR SOURCE SELECTION

Source selection criteria are divided into three parts: technical, management, and cost. The design for discard criterion should be in the technical part as heavily as feasible in view of all the other important things that are there and should be named in the management part. Important design for discard elements of the statement of work should be included quantitatively in the evaluation criteria for the source selection evaluation group and included by relative ranking in Section M, "Evaluation Factors for Award", of the solicitation.

If discardability is an important source selection evaluation criterion, it must be listed in the solicitation*, and appropriate technical people should be part of the source-selection-evaluation group, regardless of its size. Otherwise, there are no special ways in which a design for discard program affects source selection evaluation. The criteria for source selection evaluation** are explained in the Federal Acquisition Regulation (FAR), Subpart 15.4, "Solicitation and Receipt of Proposals and Quotations", and Subpart 15.6, "Source Selection" (Ref. 1).

A design for discard program can be made a significant evaluation (sub)factor in the solicitation. See par. 14-2, "Evaluation Criteria for Selection", for more information on the criteria for source selection.

A formal source selection evaluation board (SSEB) is convened only for major systems. Source selection, a segment of contracting by negotiation, is described in the FAR, Subpart 15.6 (Ref. 1). The other segment of interest to design for discard is solicitation and receipt of proposals and quotations, as addressed in the FAR, Subpart 15.4 (Ref. 1). Alternative procedures to those described in the FAR, Subpart 15.6, are allowed and are described in the Defense Federal Acquisition Regulation Supplement (DFARS) 215.613-70, "Four-Step Source Selection Procedures" (Ref. 2). The evaluation group for source selection can range from a formal SSEB of over 50 people to a small group of just a few people. The project manager should be a member of the source selection group.

17-3 STATEMENT OF WORK

The statement of work (SOW), also called a work statement, is placed in Section C, "Description/Specifications/Work Statement", of Part I, "The Schedule", of the solicitation and contract (FAR 15.406, Ref. 1).

17-3.1 PRINCIPLES

The SOW describes, among other things, the work the contractor must do that can affect but does not result in an end-item. An example is a failure mode, effects, and criticality analysis (FMECA). The principles involved in placing a design for discard program in a SOW are the same for any program. All work components of a design for discard program should be included. Basically, such work components involve two things:

1. The statement of the design for discard program plan

*"The solicitation shall clearly state the evaluation factors, including price or cost and any significant subfactors, that will be considered in making the source selection and their relative importance. Numerical weights, which may be employed in the evaluation of proposals, need not be disclosed in solicitations. The solicitation shall inform offerors of minimum requirements that apply to particular evaluation factors and significant subfactors." (Ref. 1)

**Because of the legal implications, neither the FAR nor the DFARS is explained here, other than by direct quotation. The proper Army contracting officer should be consulted for any interpretation or evaluation.

2. The implementation of the design for discard program.

The three unique elements of a design for discard program that must be addressed and implemented are awareness training, incentives for initiative, and adequate analytic tools; they are explained in par. 16-1. The design for discard program plan must show how these three unique elements are integrated with the maintainability and logistic support programs.

17-3.2 SAMPLE CLAUSES

Exhibit DFD-XXX, mentioned in this subparagraph, is outlined in Appendix B, "Exhibit DFD-XXX, Design for Discard Program", which contains example tasks for a contract. The example tasks and sample clauses should be tailored by each command to conform to its needs and policies. Sample clauses for a request for proposals (RFP) and/or contract are

1. Offeror's proposal shall include

a. A design for discard program plan that addresses the three essential elements of a design for discard program that would not otherwise be part of the acquisition. Those elements are awareness training for the program, incentives for initiative during design and manufacture, and provision of adequate analytic tools for life cycle cost (LCC) and level of repair analysis (LORA).

b. Provision of resources to implement that program plan.

2. Offeror's proposal shall include both Task 1, "Design for Discard Program Plan", from Exhibit DFD-XXX, "Design for Discard Program", and provision of resources to implement that program plan.

3. The contractor shall

a. Provide a design for discard program plan subject to approval by the Government that addresses the three essential elements of a design for discard program that would not otherwise be part of the acquisition. Those elements are awareness training for the program, incentives for initiative during design and manufacture, and provision of adequate analytic tools for life cycle cost and level of repair analysis.

b. Implement that program plan.

4. The contractor shall perform Tasks 1, 2, 3, and 4 of Exhibit DFD-XXX, "Design for Discard Program". The program plan of Task 1 is subject to the approval of the Government.

17-3.3 DATA ITEMS

A data item is the documentation that represents the output of a required task in the SOW and must be delivered to the Government. Not all documentation prepared by the contractor should be represented as data items because of the expense to the contractor and thus to the Government. It is feasible to require that certain nondata item documentation be made available for perusal by the Government at the contractor's facility.

The only two data items that should be required in a design for discard program are

1. The design for discard program plan

2. An output product that identifies discardable elements and how the decision was made, e.g., LORA results.

The contractor's progress in design for discard is more appropriately and economically measured during program reviews than it is by periodic detailed reports that list the resources devoted to the program.

17-4 INCENTIVE CLAUSES

Incentives are desirable when the Army wishes to emphasize some measure(s) of contractual performance, such as cost, delivery schedule, and/or product characteristics. If it is desirable to emphasize a design for discard program, incentives could be offered for reductions in LCC due to discardability.

The Army should analyze any incentive contract before its award. If there are incentives other than cost, the analysis must be extensive. All legal outcomes must be sampled, and the Army must be indifferent to the outcome. If the Army prefers some outcomes to others, the incentive package should be redone. Redoing the incentives might involve, for example, constraints on the performance of each kind of item as well as constraints on their combinations. This analysis ends when the Army is indifferent to any legal contractual outcome.

Fixed-price contracts and cost-reimbursement contracts are discussed in this paragraph.

17-4.1 FIXED-PRICE CONTRACTS

Fixed-price contracts are used largely for hardware production. (FAR Subpart 16.2, "Fixed-Price Contracts" (Ref. 1)) The cost risks are presumed to be reasonably well-known, and the technical risks are presumed to be small or assumed by the contractor. The Army prefers fixed-price contracts when it is feasible to use them. It is desirable to include design for discard provisions in such a contract as long as there is no undue conflict with other contractual provisions.

Fixed-price-incentive (FPI) contracts are used if firm-fixed-price (FFP) contracts are not appropriate, and some cost responsibility by the contractor via profit incentive is likely to hold down costs and improve the contractor's performance. (FAR 16.204 (Ref. 1)) There must always be an incentive on contract cost. There can also be incentives relating to item performance and delivery schedule. The contract must be written to allow the contractor appreciable management leeway so that the incentive provisions will be meaningful. Separate incentive provisions can apply to individual line items in the contract. Details of fixing the incentives are given in FAR 16.401, 16.402, and 16.403 (Ref. 1).

Before using FPI for a design for discard program, the incentives should be analyzed carefully because there is difficulty measuring the success of design for discard.

17-4.2 COST-REIMBURSEMENT CONTRACTS

Cost-reimbursement contracts are appropriate only when the uncertainties about fulfilling contract goals are so great that a fixed price contract cannot be used. (FAR, Subpart 16.3, "Cost-Reimbursement Contracts" Ref. 1)) The contractor's cost accounting must be sufficiently good that the Army can monitor cost and technical progress to be sure that time and money are not being wasted. Important restrictions on writing this type of contract are explained in FAR 16.301-3, "Limitations". These limitations apply to all the subtypes of contracts in this category.

Cost-plus-incentive-fee (CPIF) contracts are the most popular of the "cost plus" contract types. It is possible to add incentives that are based on item performance or deliveries. The purpose of the incentive fee on cost is to provide the contractor with a real incentive to hold costs down. The incentive considerations are similar to those for FPI contracts.

Cost-plus-award-fee (CPAF) contracts are preferred over the incentive fee when the incentive objectives are difficult to measure. The fee is in two parts, a fixed minimum fee and a variable award fee. The flexibility of CPAF in rewarding good contractor performance makes this a feasible alternative for development contracts in which design for discard results are essential. The amount of the award fee is decided unilaterally by the Army and is not subject to the disputes clause of the contract. The FAR discusses the details of the award fee at length.

17-5 SPECIFICATION REQUIREMENTS

The following kinds of design for discard requirements can feasibly be in a contract:

1. A program plan for design for discard
2. Investigation of alternative materials and processes
3. Creation and analysis of alternative designs
4. Specification of the LORA programs to be used (or not used).

Because the engineering state of the art is changing so rapidly and because the LORA programs of the Army are being improved, it is difficult to foresee how much the level of discardability can feasibly be raised.

Exhibit DFD-XXX, outlined in Appendix B, "Exhibit DFD-XXX, Design for Discard Program", can be used to invoke a design for discard program. It should be tailored by each command to conform to its needs and policies.

17-6 INSPECTION AND ACCEPTANCE

This paragraph discusses the contractual functions of product inspection and acceptance. These contractual functions are the same whether or not a contract requires a design for discard program. For many components the inspection and acceptance procedures are the same, regardless of the discardability of the components. The opportunities and difficulties in inspection and acceptance are

1. *Opportunities*:

   a. If a simple, inexpensive Go/NoGo test for the discardable unit is adequate for all purposes, inspection and acceptance would be simpler than for a nondiscardable unit.

   b. Many types of items designed for discard should have a higher quality, i.e., a lower fraction of nonconforming items in the lot, due to the design for discard program and/or to the total quality efforts being implemented by the Army and industry. In such cases the sample size to be tested for each lot and the depth of test on each discardable unit can be considerably reduced.

2. *Difficulties*:

   a. If discardability also means that the internal workings of the component are less accessible than for a repairable component, the discardable parts might be more difficult to test thoroughly, e.g., for internally degraded operation, and nondestructively.

   b. In any production system some elements of an assembly become covered up as the assembly progresses. Testing of those elements must be done before they are covered up. Generally, the only way a customer can be assured of the proper quality is to monitor the manufacturing process and thus be assured that the process is consistent and correct.

Par. 14-3, "Quality Assurance", addresses this subject in more detail.

17-7 WARRANTIES

Warranty considerations are exactly the same whether or not a contract requires a design for discard program. The primary source of information on warranties associated with weapon systems is DFARS 46.770, "Use of Warranties in Weapon System Procurements" (Ref. 2). Secondary sources are publications of the US Army Materiel Command (AMC) and the cognizant command and the contracting officer. Other sources should not be used because of the complex, changing nature of the rules and regulations imposed by Congress and the Department of Defense (DoD).* Appendix C, "Warranty Regulations", provides information adapted from the FAR (Ref. 1) and DFARS (Ref. 2).

The three principal purposes of a warranty are

1. To delineate the rights and obligations of the contractor and the Government for defective items and services
2. To foster quality performance
3. To allow the Government additional time after acceptance to assert its rights.

*For this reason, no detailed information on applying warranties is given in this handbook.

The following five factors ought to be considered together in deciding on the inclusion of a warranty:

1. Nature of the item
2. Cost of the warranty to both the contractor and Government
3. Administration and enforcement
4. Trade (commercial) practice of no-extra-cost warranties
5. Reduced quality assurance requirements.

Explicit commercial warranties are generally short-term agreements to repair or replace a product due to defects in materials or workmanship. These can be used, but the logistic cost to the Army to take advantage of the warranty can negate its value. Discardable items could provide a better opportunity to use a commercial warranty. If feasible, the Army should obtain prices with and without the commercial warranty and then decide which way would be more cost-effective.

The reliability improvement warranty (RIW) is the most well-known and popularized of the military warranties, even though there are not many complete case histories published on how well it has actually worked. The RIW works best on self-contained units that are easily sealed and easily testable (remove and replace concept). This way, the contractor is not accountable for any tampering or incorrect maintenance by the Army. Discardable units fit into this category and are thus very appropriate for an RIW. Whether the contractor repairs the returned units or replaces them with new units is of no concern to the Army. The RIW is discussed further in Appendix D, "Reliability Improvement Warranty".

17-8 SECOND SOURCING

If only one contractor is producing an item, it is often desirable to find a second source to produce the item also. The reasons for this are

1. There is competition among the contractors, which can improve both price and delivery.
2. The item is less likely to be completely unavailable, e.g., due to strikes, accidents, and/or natural disasters.

This procedure is called "second sourcing". If the technical data package (TDP) is excellent, i.e., the product and processes are well-characterized, there is little difficulty bringing a second contractor on line.

Second sourcing is common commercial practice for critical items in production. Even with very proprietary products and processes, large customers often insist that the original supplier bring a second source on line. The exact proportion of second sourcing will depend on the nature of current business practices and the cost vs supply risks the Army is willing to take.

Competition among contractors is an excellent way to encourage the competing contractors to use creative engineering to enhance the economic discardability of an item. Their incentive is not in any explicit contractual incentives; it is in knowing that economic discardability will be important in choosing a contractor.

Second sourcing and design for discard are very compatible; the discardability requirements introduce no new complexities into the second-sourcing process. Insofar as second sourcing encourages competition among contractors, it will help the design for discard program. Second-source contracts can include design for discard* provisions, regardless of the original discardability of the item or its components.

REFERENCES

1. *Federal Acquisition Regulation (FAR)*, Title 48, Federal Acquisition Regulations System, Chapter I, US Government Printing Office, Washington, DC, 1 April 1984 (1990 Ed.).
2. *Defense FAR Supplement (DFARS)*, US Government Printing Office, Washington, DC, 31 December 1991.

BIBLIOGRAPHY

AR 715-6, *Proposal Evaluation and Source Selection*, 21 September 1970.

*Any changes in the design should be subject to form, fit, function, and testability provisions.

APPENDIX A
GENERAL INFORMATION SOURCES

A-1 ENGINEERING PROFESSIONAL SOCIETIES

The major engineering societies are among the largest technical publishers in the world. They publish professional journals, technical magazines, standards, pamphlets, books, and proceedings of conferences and symposia. Some of the societies are listed here with their current mailing addresses and telephone numbers. Many of the societies are umbrella organizations with many subsocieties.

A-1.1 American Institute of Aeronautics and Astronautics (AIAA)
370 L'Enfant Promenade, SW
Washington, DC 20024-2518
Phone: 202-646-7400

A-1.2 American Society of Mechanical Engineers (ASME)
345 East 47th Street
New York, NY 10017
Phone: 212-705-7745

A-1.3 American Society for Quality Control (ASQC)
611 East Wisconsin Avenue
PO Box 3005
Milwaukee, WI 53201
Phone: 414-272-8575

A-1.4 ASM International (formerly: American Society for Metals)
Materials Park, OH 44073-0002
Phone: 216-338-5151

A-1.5 Institute of Electrical and Electronics Engineers (IEEE)
345 East 47th Street
New York, NY 10017
Phone: 212-705-7900

A-1.6 Institute of Environmental Sciences (IES)
940 Northwest Highway
Mount Prospect, IL 60056
Phone: 708-255-1561

A-1.7 Institute of Industrial Engineers (IIE)
25 Technology Park/Atlanta
Norcross, GA 30092
Phone: 404-449-0460

A-1.8 SAE International (formerly: Society of Automotive Engineers)
400 Commonwealth Drive
Warrenton, PA 15096-0001
Phone: 412-776-4841

A-1.9 Society of Logistics Engineers (SOLE)
8100 Professional Place, Suite 211
New Carrollton, MD 20785-2225
Phone: 301-459-8446

A-1.10 Society of Manufacturing Engineers (SME)
1 SME Drive
PO Box 930
Dearborn, MI 48121
Phone: 800-733-4SME

A-1.11 System Safety Society (SSS)
Five Export Drive, Suite A
Sterling, VA 22170-4421
Phone: 703-450-0310

A-2 TRADE MAGAZINES

The following list gives several publishers, their pertinent magazines, and a few words about magazine content and/or intended readership. There are other publishers and magazines that can also be useful.

A-2.1 Cahners Publishing Company
275 Washington Street
Newton, MA 02158-1630
Phone: 800-662-7776

Control Engineering, engineers who design, install, and maintain automatically controlled systems

Datamation, information processing

Design News, design engineers

EDN, electronics design engineers

Electronic Packaging & Production, concurrent engineering for packaging, fabrication, and assembly

Highway & Heavy Construction, highway and other heavy construction

Packaging, packaging for industrial, consumer, and commercial products

Plant Engineering, maintaining plant facilities, equipment, and systems

Plastics World, plastics designers and processors

Pollution Engineering, equipment for control of air, water, and wastes

Research & Development, scientists and engineers in applied research

Semiconductor International, designers and manufacturers of semiconductors

Systems Integration, designers of computer systems for business and industry

Test & Measurement World, test and inspection of electronics

A-2.2 Cardiff Publishing Company
6300 South Syracuse Way, Suite 650
Englewood, CO 80111
Phone: 303-220-0600

Defense Electronics, electronics technology

Radio Frequency

A-2.3 Nelson Publishing
2504 North Tamiami Trail
Nokomis, FL 34275-3482
Phone: 813-966-9521

EE Evaluation Engineering, electronic evaluation and test

A-2.4 McGraw-Hill
1221 Avenue of the Americas
New York, NY 10020
Phone: 212-512-2000

Modern Plastics, plastics industry and technology

A-2.5 Miller Freeman, Inc.
600 Harrison Street
San Francisco, CA 94107
Phone: 415-905-2200

AI Expert, artificial intelligence and expert systems

Circuits Assembly, surface-mount and board level assembly

Printed Circuit Design, design of printed circuit boards

Printed Circuit Fabrication, fabrication of printed circuit boards

A-2.6 Penton Publishing Company, Inc.
1100 Superior Avenue
Cleveland, OH 44114
Phone: 216-696-7000

Automation, manufacturing/production engineering and management

American Machinist, metalworking industries

Casting Design & Application, casting design

Computer-Aided Engineering, users of computer-based equipment

Electronic Design, design engineering

Hydraulics & Pneumatics, fluid power and controls

Foundry Management & Technology, foundry industry

Machine Design, design engineering

Materials Engineering, materials specifiers and evaluators

Microwaves & RF, microwave and radio-frequency engineering

Occupational Hazards, industrial safety, health, and environment

Welding Design and Fabrication, welding and metal fabrication

APPENDIX B
EXHIBIT DFD-XXX
DESIGN FOR DISCARD PROGRAM*

B-1 SCOPE

This exhibit is a supplement to MIL-STD-470 to satisfy the needs of the Army for a design for discard program.

B-2 REFERENCED DOCUMENT

MIL-STD-470, *Maintainability Program for Systems and Equipment*.

B-3 DEFINITIONS

[None]

B-4 GENERAL REQUIREMENTS

B-4.1 DESIGN FOR DISCARD PROGRAM

The design for discard program of a contractor shall comply with

1. Provisions of this exhibit
2. Provisions of the contract statement of work.

B-4.2 PROGRAM INTEGRATION

The design for discard program shall be used only when both quantitative reliability requirements and quantitative maintainability requirements exist.

The contractor shall, insofar as is feasible, integrate the task requirements of this exhibit with other task requirements related to reliability, maintainability, and logistic support.

B-4.3 QUALITATIVE REQUIREMENTS

The following qualitative requirements shall be implemented:

1. The design for discard program of the contractor shall strengthen the Army's effort to

 a. Strive for the lowest, total cost of an effective maintenance and logistic support system rather than merely the lowest direct cost of repair operations and replacement parts.

 b. Let the commercial marketplace operate to reduce the cost of such a system.

2. The discardability of components shall in consonance with other military objectives be enhanced by creative engineering associated with diagnostics, physical arrangement, material selection, and fabrication.

3. If form, fit, and function are imposed upon a component, the concept of function shall include

 a. Interactions with other components, especially transient interactions

 b. Diagnostics, especially the risks associated with incorrect diagnosis.

4. Design for discard should be an explicit part of each program review for which discardability is pertinent.

B-5 SPECIFIC REQUIREMENTS

B-5.1 DESIGN FOR DISCARD PROGRAM PLAN (TASK 1)

The contractor shall prepare a design for discard program plan that shall include but not be limited to Tasks 2, 3, and 4 of this exhibit.

B-5.2 AWARENESS TRAINING (TASK 2)

Engineers and managers must be made aware of

1. The importance of discardability at a high assembly level (hardware indenture level) as a product characteristic

2. The need for aggressive and creative engineering initiative to achieve discardability in consonance with other military objectives.

3. The exigency of analytic models for life cycle cost (LCC) and level of repair analysis (LORA) that have been upgraded to encompass all long-term costs for discardability evaluation.

B-5.3 INCENTIVES FOR INITIATIVE (TASK 3)

The product and project requirements must include provisions that encourage engineers and managers to take aggressive and creative initiative to raise the assembly level at which discard could occur.

B-5.4 ADEQUATE ANALYTIC TOOLS (TASK 4)

The models (and parameters therein) that engineers use for life cycle cost analysis and level of repair analysis must adequately reflect the long-term goal of the Army to reduce the resources devoted to supporting each soldier in the field. For example, the long-term costs of training facilities and personnel and of the logistic support system must be included in the models in such a way that decreases in long-term costs can outweigh some increases in short-term costs.

*Portions of this exhibit have been modeled upon and/or adapted from Exhibit QR-870-J from the US Army Missile Command (MICOM).

B-6 NOTES

All of the tasks that must be done in any acquisition in which there are quantitative reliability and maintainability (R&M) requirements must also be done when such acquisition involves a design for discard program. For example, life cycle cost analysis and level of repair analysis are essential tools in such an acquisition, regardless of the presence of a design for discard program.

Thus only those tasks that must be performed in addition to the usual R&M tasks are listed in this exhibit.

APPENDIX C
WARRANTY REGULATIONS

C-1 SOURCE LISTINGS

The Federal Acquisition Regulation (FAR) (Ref. 1) and its DoD Supplement (DFARS) (Ref. 2) deal at length with warranties and their ramifications. Anyone who contemplates using a warranty should become familiar with the current rules and regulations regarding warranties.* Because the FAR and DFARS do change, they are not quoted here at length. The lists that follow are from these regulations and indicate their pertinent contents. Specific FAR and DFARS** numbers and titles related to warranties follow:

FAR 46.7, "Warranties"
- 46.701, "Definitions"
- 46.702, "General"
- 46.703, "Criteria for use of warranties"
- 46.704, "Authority for use of warranties"
- 46.705, "Limitations"
- 46.706, "Warranty terms and conditions"
- 46.707, "Pricing aspects of fixed price incentive contract warranties"
- 46.708, "Warranties of data"
- 46.709, "Warranties of commercial items"
- 46.710, "Contract clauses" (See also 52.246.).

The DFARS 246.704, "Authority for use of warranties", is merely a short statement that refers to DFARS 246.770, "Warranties in weapon system acquisitions", for warranties in the procurement of weapon systems. The list that follows indicates the contents (number and title) of DFARS 246.770:

DFARS 246.770, "Use of warranties in weapon system procurements"
- 246.770-1, "Definitions"
- 246.770-2, "Policy"
- 246.770-3, "Tailoring warranty terms and conditions"
- 246.770-4, "Warranties on Government-furnished property"
- 246.770-5, "Exemption for alternate source contractor(s)"
- 246.770-6, "Applicability to foreign military sales (FMS)"
- 246.770-7, "Cost-benefit analysis"
- 246.770-8, "Waiver and notification procedures".

The DFARS explicitly defines weapon systems (DFARS 246.770-1) and classifies all supplies as either weapon systems or not (DFARS 246.703). Thus the approach to warranties depends on the classification of the item.

C-2 USE OF VARIATIONS AND JUDGMENT

In all situations the contracting officer is expected to use appreciable judgment to decide whether a warranty is appropriate and, if so, to select the appropriate variation of the allowed clause.† Some specific categories of supply types and their references are

1. Supplies of a noncomplex nature, FAR 46.710(a)
2. Supplies of a complex nature, including those for research and development, FAR 46.710(b)
3. Items for which performance specifications or design are very important and for which a fixed price supply, service, or research and development contract for systems and equipment is contemplated, FAR 46.710(c)
4. Except for appropriate clauses concerning inspection of received items, the use of warranties is discouraged in cost reimbursement contracts, FAR 46.705, "Limitations".

C-3 SOURCES OF WARRANTY ADVICE

The primary source of information on warranties associated with weapon systems is DFARS 246.770, "Use of warranties in weapon system procurements". Secondary sources are publications of the US Army Materiel Command (AMC) and the cognizant command and the contracting officer. Other sources should not be used because of the very complex and changing nature of the rules and regulations imposed by Congress and the Department of Defense (DoD).

REFERENCES

1. *Federal Acquisition Regulation (FAR)*, Title 48, Federal Acquisition Regulations System, Chapter I, US Government Printing Office, Washington, DC, 1 April 1984 (1990 Ed.).
2. *Defense FAR Supplement (DFARS)*, US Government Printing Office, Washington, DC, 31 December 1991.

*The discussion in this appendix is intended for readers who may not be as familiar with the FAR and DFARS as those who use them on a daily basis.

**The DFARS numbering system corresponds to the FAR numbering system, and the DFARS numbers begin with an added "2". For example, DFARS 246.701 "Definitions", corresponds to FAR 46.701 "Definitions"; DFARS 246.770 "Warranties in weapon system acquisitions", extends the FAR Subpart 46.7, "Warranties".

†The discussion in this appendix is intended for readers who may not be as familiar (a) with the FAR and DFARS as those who use them on a daily basis and (b) in particular, with the latitude and authority given to the contracting officers.

APPENDIX D
RELIABILITY IMPROVEMENT WARRANTY

D-1 PURPOSE

The primary purpose of the reliability improvement warranty (RIW)* is to motivate a contractor to improve the reliability of an item by means of no-cost (to the Army) engineering changes. The contractor has this motivation because he has a long-term contract to "repair or replace a group of items at a fixed price for the group" for a "fixed length of calendar time", regardless of how often they fail. Therefore, he can spend some money to lengthen their lives and more than recoup the investment by not having to repair or replace them. For an RIW to motivate the RIW contractor effectively, the time period of the warranty must be at least several mean times to failure (MTTF). That is, the RIW contractor anticipates servicing each item several times unless he improves the MTTF by changing the design of the item or methods used to manufacture it.

D-2 IMPLEMENTATION

The mechanism for implementing a no-cost engineering change is the engineering change proposal (ECP)—just as if the change were an ordinary one. The difference is in the handling of the ECP by the Army and the contractor. The motivation of the contractor to improve the product life removes much red tape and negotiation cost of the ECPs and thus saves additional resources for both the Army and the contractor. The ECPs are simpler because they are no cost to the Army. Time is saved because the Army rarely negotiates about the ECPs since the technical and cost risks therein are voluntarily assumed by the contractor, not the Army.

D-3 PLANNING

If an RIW is planned for an item, the following two things must be done during development:

1. The RIW is included in the development solicitation for the item and is explicitly part of the evaluation criteria.

2. The plan for RIW is included in the development contract so that the contractor can make suitable tradeoffs during development.

*The RIW is not mentioned explicitly in the FAR or DFARS but is generally considered compatible with those regulations.

GLOSSARY

Some of the words and phrases have complicated, detailed, mathematical, and/or many definitions, some of which depend on context. The definitions given here are intended only to explain the general concept; they should not be used as complete explanations. Multiple definitions are indicated by numbers in [ ]; the sequence does not indicate importance.

A

Acquisition. "...The acquiring by contract with appropriated funds of supplies and services by and for the use of the Federal Government through purchase or lease...." (FAR 2.101). It is the most general and all encompassing word that relates to the acquiring of an item by the Army. *See also* Acquisition Process.

Acquisition Process. "The sequence of acquisition activities beginning with the Army's reconciliation of its mission needs with its capabilities, priorities, and resources, and extending through the deployment of a system." (Ref. 1)

Availability. "The fraction of time that the system is actually capable of performing its mission." (Ref. 2)

C

Characterize. Knowledge of all the properties and interactive relationships that are important for the purposes at hand. The word applies to items, processes, environments, etc. For example, during test and repair a repairable unit is characterized if one knows exactly what to test for, how to test it, how to interpret the results, what to fix, and how to fix it. Nothing can ever be completely characterized for all situations simply because science is not complete. Interfaces between items are usually incompletely characterized simply because not enough resources have been devoted to the problem and/or the purposes at hand have changed.

Combat Resilience. "A weapon-system characteristic that permits an incapacitated weapon system to be restored quickly to some needed, useful (possibly degraded) operational capability, with the expedient resources available on the battlefield." (Ref. 3)

Configuration Control. "The systematic proposal, justification, evaluation, coordination, approval or disapproval, and implementation of all approved changes in the configuration of a configuration item after formal establishment of the baseline." (Ref. 4)

Configuration Item. "An aggregation of hardware, firmware, or other computer software or any of their discrete portions, which satisfies an end use function and is designated by the Government for separate configuration management. Configuration items may vary widely in complexity, size, and type, from an aircraft, electronic, or ship system to a test meter or round of ammunition. Any item required for logistic support and designated for separate procurement is a configuration item." (Ref. 4)

Configuration Management. "The technical and administrative direction and surveillance actions taken to identify and document the functional and physical characteristics of a configuration item; to control changes to a configuration item and its characteristics; and to record and report change processing and implementation status." (Ref. 4)

Criticality Analysis. "A procedure by which each potential failure mode is ranked according to the combined influence of severity and probability of occurrence." (Ref. 5)

D

Database. Any collection of information structured so the desired kinds of information can be extracted reasonably from it. Very often a database resides on a computer storage-medium and is structured by a computer program.

Design to Cost. "An acquisition management cost control technique established to achieve defense system designs that meet stated cost requirements. Cost is a design requirement addressed on a continuing basis as part of a system's development process. The technique embodies early establishment of realistic but rigorous cost objectives, goals, and a determined effort to achieve them." (Ref. 6)

Design to Life Cycle Cost. A special case of design to cost in which the cost of concern is the life cycle cost.

Design to Unit Production Cost. "That cost established prior to the development of an item to guide design and to control program costs. It is the cost to the Government to acquire a production item based on a stated level of production. It is established early in development to insure from the start that engineers design and develop an item that will not cost more than the Army can afford to pay for the item." (Ref. 7)

Diagnosis. "The functions performed and the techniques used in determining and isolating the cause of malfunctions." (Refs. 8 and 9)

Down. An item is not in a condition to perform its intended function.

Durability. "A special case of reliability; the probability that an item will successfully survive its projected life, overhaul point, or rebuild point (whichever is the more appropriate durability measure for the item) without a durability failure." (Ref. 10)

End-Item. "A final combination of end-products, component parts, and/or materials that is ready for its intended use; e.g., ship, tank, mobile machine shop, aircraft." (Ref. 11)

Failure Mode and Effects Analysis. "A procedure by which each potential failure mode in a system is analyzed to determine the results or effects thereof on the system and to classify each potential failure mode according to its severity." (Ref. 5)

Failure Mode, Effects, and Criticality Analysis. "...an analysis procedure which documents all probable failures in a system within specified ground rules, determines by failure mode analysis the effect of each failure on system operation, identifies single failure points, and ranks each failure according to a severity classification of failure effect." (Ref. 5)

Functional Test. [1] "A test which determines whether the UUT [unit under test] is functioning properly. The operational environment (such as stimuli and loads) can be either actual or simulated." (Ref. 9) [2] A test that checks the overall performance characteristics of an item under benign conditions and with benign criteria for pass or fail (Go/NoGo). It is a qualitative term whose meaning changes with the available technology.

G

Go/No-Go Test. "A test designed to yield a *test pass* or *go* indication in the absence of faults in a UUT [unit under test], and a *test fail* or *no-go* indication when faults have been detected." (Ref. 9)

I

Incentive Contract. "A subclass of contract types that relate[s] the amount of profit or fee payable under the contract to the contractor's performance. The subclass applies to fixed-price and cost-reimbursement classes of contracts." (FAR 16.401)

Integrated Logistic Support. "A disciplined, unified, and iterative approach to the management and technical activities necessary to integrate support considerations into system and equipment design; develop support requirements that are related consistently to readiness objectives, to design, and to each other; acquire the required support; and provide the required support during the operational phase at minimum cost." (Ref. 12)

L

Life Cycle Cost. "The total cost to the Government of acquisition and ownership of that system over its useful life. It includes the cost of development, acquisition, support and, where applicable, disposal." (Ref. 12)

Logistic Support. "Provision of adequate materiel and services to a military force to assure successful accomplishment of assigned missions." (Ref. 7)

Logistic Support Analysis. "The selective application of scientific and engineering efforts undertaken during the acquisition process, as part of the systems engineering process, to assist in: causing support considerations to influence design; defining support requirements that are related optimally to design and to each other; acquiring the required support; and providing the required support during the operational phase at minimum cost." (Ref. 12)

M

Maintenance. "All actions necessary for retaining an item in, or restoring it to, a serviceable condition. Maintenance includes servicing, repair, modification, overhaul, inspection, and condition determination." (Ref. 13)

Maintainability. "The ability of an item to be retained in or restored to specified condition when maintenance is performed by personnel having specified skill levels, using prescribed procedures and resources, at each prescribed level of maintenance and repair." (Ref. 12)

Maintainability Growth. The improvement in maintainability measures of an item due to corrective action. It is directly analogous to reliability growth, in both concept and practice.

Mobility. "A quality or capability of military forces which permits them to move from place to place while retaining the ability to fulfill their primary mission." (Ref. 14)

N

Nondevelopmental Item. [1] "An item available from a variety of sources and requiring virtually no development effort by the Army." (Ref. 15)

[2] "a. Any item of supply that is available in the commercial marketplace;

b. Any previously developed item of supply that is in use by a department or agency of the United States, a State or local government, or a foreign government with which the United States has a mutual defense cooperation agreement;

c. Any item of supply described in definition 82*.a. or b., above, that requires only minor modification in order to meet the requirements of the procuring agency; or

d. Any item of supply that is currently being produced that does not meet the requirements of 82*.a., b., or c., above, solely because the item is not yet in use or is not yet available in the commercial marketplace." (Ref. 12)

*"82" refers to the definition number in Ref. 12.

O

Operational Readiness. "The capability of a unit/formation, ship, weapon system, or equipment to perform the missions or functions for which it is organized or designed. May be used in a general sense or to express a level or degree of readiness." (Ref. 14)

P

Partitioning. Physically grouping the items of a system according to a set of rules with the intent that some particular groups will be modules. A name is often given to the set of rules and their intent, and that name is used to modify "partitioning", e.g., cost partitioning.

Procurement. "The process of obtaining personnel, services, supplies and equipment." (Ref. 14)

Purchase Description. "...a description of the essential physical characteristics and functions required to meet the Government's minimum needs." (FAR 10.001)

R

Readiness. "The ability of forces, units, weapon systems, or equipments to deliver the outputs for which they were designed (includes the ability to deploy and employ without unacceptable delays)." (Ref. 14) *See also* Operational Readiness.

Reliability. "A measure of the ability of an item to complete its mission successfully." (Ref. 2)

Resources. A general word that includes the people, time, and money needed for a project or task.

S

Second Source. Another contractor who will develop, produce, or sell an item in addition to, not in place of, the original contractor.

Sole Source Acquisition. "...a contract for the purchase of supplies or services that is entered into or proposed to be entered into by an agency after soliciting and negotiating with only one source." (FAR 6.003)

Solicitation. "A request for proposals or quotations." (FAR 15.407)

Specification. "...a description of the technical requirements for a material, product, or service that includes the criteria for determining whether these requirements are met. Specifications shall state only the Government's actual minimum needs and be designed to promote full and open competition, with due regard to the nature of the supplies or services to be acquired." (FAR 10.001)

Subcontractor. "...any supplier, distributor, vendor, or firm that furnishes supplies or services to or for a prime contractor or another subcontractor." (FAR 44.101)

Sustainability. "The ability to maintain the necessary level and duration of combat activity to achieve national objectives. Sustainability is a function of providing for and maintaining those levels of ready forces, materiel, and consumables necessary to support a military effort." (Ref. 14)

System Effectiveness. "A summary measure of the ability of a complex system to satisfy the needs of its users." (Ref. 2)

T

Technical Data Package (TDP). "A technical description of an item adequate for supporting an acquisition strategy, production, engineering, and logistics support. The description defines the required design configuration and procedures to ensure adequacy of item performance. It consists of all applicable technical data such as drawings, associated lists, specifications, standards, performance requirements, quality assurance provisions, and packaging details." (Ref. 12)

Testability. "A design characteristic which allows the status (operable, inoperable, or degraded) of an item to be determined and the isolation of faults within the item to be performed in a timely manner." (Ref. 8)

Tradeoff. An engineering and management technique by which to reach a compromise when the decision is limited by constraints.

U

Up. The condition of an item or equipment to perform its intended function.

W

Work Breakdown Structure. "A product oriented family tree composed of hardware, software, services, and other work tasks which results from project engineering efforts during the development and production of defense materiel items, and which completely defines the project/program. A work breakdown structure displays and defines the product(s) to be developed or produced and relates the elements of work to be accomplished to each other and to the end product." (Ref. 7)

REFERENCES

1. OMB Circ. A-109, *Major System Acquisitions*, 5 April 1976.
2. AMCP 706-200, Engineering Design Handbook, *Development Guide for Reliability, Part Six, Mathematical Appendix and Glossary*, January 1976.
3. William M. Shepherd, "AirLand Battle in the 21st Century", *Proceedings: Annual Reliability & Maintainabil-*

ity Symposium, Los Angeles, CA, January 1988, pp. 40-5, The Institute of Electrical and Electronics Engineers, Inc., New York, NY.

4. MIL-STD-973, *Configuration Management*, 17 April 1992.
5. MIL-STD-1629A, *Procedures for Performing a Failure Mode, Effects, and Criticality Analysis*, 24 November 1980.
6. MIL-HDBK-766, *Design to Cost*, 25 August 1989.
7. AR 310-25, *Dictionary of United States Army Terms*, 15 September 1975.
8. MIL-STD-2165, *Testability Program for Electronic Systems and Equipment*, 26 January 1985.
9. MIL-STD-1309C, *Definitions of Terms for Test, Measurement, and Diagnostic Equipment*, 18 November 1983.
10. TRADOC/AMC-P 70-11, *RAM Rationale Report Handbook*, 1 July 1987.
11. MIL-STD-881A, *Work Breakdown Structures for Defense Materiel Items*, 25 April 1975.
12. DoD Instruction 5000.2, *Defense Acquisition Management Policies and Procedures*, 23 February 1991.
13. DoD-HDBK-791(AM), *Maintainability Design Techniques*, 17 March 1988.
14. Joint Publication 1-02, *Department of Defense Dictionary of Military and Associated Terms*, 1 December 1989.
15. AR 70-1, *System Acquisition Policies and Procedures*, 31 March 1993.

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SUBJECT TERM (KEY WORD) LISTING

Analysis and decision techniques
Creative designs
Concept
Design consideration
Discardable unit
Fabrication
Functional grouping
Hardware indenture level
Integrated logistic support
Inventory
Level of repair analysis
Life cycle costs
Logistic support analysis
Maintainability
Manpower and personnel integration
Materials
Models
Modular construction
Operational analysis
Partitioning
Producibility
Replenishment
Testability
Tooth-to-tail ratio

Custodian:
Army—AR

Review activities:
Army—AL, AM, AT, AV, CR, MI, TM

Preparing activity:
Army—AR

(Project GDRQ-A153)

STANDARDIZATION DOCUMENT IMPROVEMENT PROPOSAL

INSTRUCTIONS

1. The preparing activity must complete blocks 1, 2, 3, and 8. In block 1, both the document number and revision letter should be given.
2. The submitter of this form must complete blocks 4, 5, 6, and 7.
3. The preparing activity must provide a reply within 30 days from receipt of the form.

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I RECOMMEND A CHANGE:	1. DOCUMENT NUMBER	2. DOCUMENT DATE *(YYMMDD)*
	MIL-HDBK-798(AR)	940204

3. DOCUMENT TITLE

System Engineer's Design for Discard Handbook

4. NATURE OF CHANGE *(Identify paragraph number and include proposed rewrite, if possible. Attach extra sheets as needed.)*

5. REASON FOR RECOMMENDATION

6. SUBMITTER

a. NAME *(Last, First, Middle Initial)*	b. ORGANIZATION	
c. ADDRESS *(Include Zip Code)*	d. TELEPHONE *(Include Area Code)*	7. DATE SUBMITTED *(YYMMDD)*

8. PREPARING ACTIVITY

a. NAME	b. TELEPHONE *(Include Area Code)*	
US Army Armament Research, Development, and Engineering Center	(1) Commercial 201-274-6671/6675	(2) DSN 880-6671/6675
c. ADDRESS *(Include Zip Code)* SMCAR-BAC-S Picatinny Arsenal, NJ 07806-5000	IF YOU DO NOT RECEIVE A REPLY WITHIN 45 DAYS, CONTACT: Defense Quality and Standardization Office 5203 Leesburg Pike, Suite 1403, Falls Church, VA 22041-3466 Telephone (703) 756-2340 AUTOVON 289-2340	