AMC PAMPHLET

ENGINEERING DESIGN HANDBOOK

MAINTENANCE ENGINEERING TECHNIQUES

HEADQUARTERS, US ARMY MATERIEL COMMAND JUNE 1975

AMCP 706-132

DEPARTMENT OF THE ARMY
HEADQUARTERS UNITED STATES ARMY MATERIEL COMMAND
5001 Eisenhower Ave, Alexandria, VA 22333

AMC PAMPHLET
NO. 706-132

30 June 1975

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LIST OF ABBREVIATIONS AND ACRONYMS

A

ADP	Automatic Data Processing
AIF	Army Industrial Fund
ALPHA	AMC Logistic Program Hardcore Automated
AMC	Army Materiel Command
ARMCOM	Armament Command
ASARC	Army Systems Acquisition Review Council
ATE	Automatic Test Equipment
AVSCOM	Aviation Systems Command

B

BITE	Built-in Test Equipment

C

CBR	Chemical, Biological, and Radiological.
CCEDR	Capability/Capacity and Engineering Data Report
CCSS	Commodity Command Standard System
CFP	Concept Formulation Package
COBOL	Common Business Oriented Language
COMSEC	Communication Security
CONUS	Continental United States
CRRC	Construction Requirement Review Committee
CWA	Central Workloading Activity

D

DA	Department of the Army
DCS	Deputy Chief of Staff
DCP	Development Concept Paper
DED	Data Element Definition
DMDB	Depot Maintenance Data Bank
DMWR	Depot Maintenance Work Requirement
DoD	Department of Defense
DSARC	Defense Systems Acquisition Review Council
DT	Development Test
DT&E	Development Test and Evaluation
DX	Direct Exchange

E

ECOM	Electronics Command
ECP	Engineering Change Proposal
EIR	Equipment Improvement Recommendation
ESC	Equipment Serviceability Criteria

LIST OF ABBREVIATIONS AND ACRONYMS (Cont'd)

F

FMEA	Failure Mode and Effects Analysis
FORTRAN	Formula Translation

G

GFE	Government-furnished Equipment
GPSS	General-purpose System Simulation

I

I&L	Installations and Logistics
IPR	In-process Review
IROAN	Inspect and Repair Only as Necessary
IRPRL	Initial Repair Part Requirement List

L

LED	Light Emitting Diode
LO	Lubrication Order
LP	Limited Procurement
LRU	Line Replaceable Unit
LSAR	Logistic Support Analysis Record

M

MAC	Maintenance Allocation Chart
MCA	Military Construction, Army
MDT	Mean Down Time
MICOM	Missile Command
MIDA	Major Item Data Agency
MOS	Military Occupational Specialty
MRC	Maintenance Requirement Card
MTBF	Mean Time Between Failures
MTBM	Mean Time Between Maintenance
MTTR	Mean Time To Repair
MWO	Modification Work Order

N

NICP	National Inventory Control Point
NMP	National Maintenance Point
NORM	Not Operationally Ready, Maintenance
NORS	Not Operationally Ready, Supply

LIST OF ABBREVIATIONS AND ACRONYMS (Cont'd)

O

O&M	Operation and Maintenance
OMA	Operation and Maintenance, Army
OR	Operational Readiness
OT	Operational Test
OT&E	Operational Test and Evaluation

P

PIMO	Presentation of Information for Maintenance and Operation
PMAC	Preliminary Maintenance Allocation Chart
PMI	Preventive Maintenance, Intermediate
PMP	Preventive Maintenance, Periodic
PS	Preventive Service
PSR	Program Status Report

R

R&D	Research and Development
RDT&E	Research, Development, Test, and Evaluation
RFP	Request for Proposal
RPSTL	Repair Part and Special Tool List

S

S&A	Supply and Administrative
SAIE	Special Acceptance Inspection Equipment
SE	System Effectiveness
SPEED	System-wide Project for Electronic Equipment at Depots
SPEEDEX	System-wide Project for Electronic Equipment at Depots, Extended
SQAP	Supplemental Quality Assurance Procedure
STD	Standard

T

TACOM	Tank-Automotive Command
TAMMS	The Army Maintenance Management System
TDA	Table of Distribution and Allowances
TECOM	Test and Evaluation Command
TMDE	Test, Measurement, and Diagnostic Equipment
TOE	Table of Organization and Equipment
TROSCOM	Troop Support Command

U

USASA	United States Army Security Agency

PREFACE

The fundamental purpose of this handbook, *Maintenance Engineering Techniques,* is to provide authoritative information requisite to the planning and implementation of effective maintenance engineering programs. A comprehensive discussion of maintenance engineering functions that must be accomplished in order to insure cost-effective acquisition, operation, and support of Army materiel is presented. The general method of presentation is to define a function and its importance, and then to provide basic information on when the function should be accomplished and the techniques that should be used.

Although written primarily for maintenance engineers, the handbook is structured with a wider audience in mind. The level of detail and manner of presentation make the handbook useful for the orientation and guidance of new personnel, Army contractors, and personnel in engineering disciplines such as system design, reliability, maintainability, safety, and human engineering. Additionally, management personnel may improve their understanding of the scope and importance of maintenance engineering by reading the handbook. Use of the handbook by this wider audience is encouraged. A greater understanding of maintenance engineering by the management and engineering disciplines with which it interfaces will result in more cost-effective Army materiel.

The handbook was prepared by the Orlando Division of Martin Marietta Aerospace under subcontract to the Engineering Handbook Office of the Research Triangle Institute, Research Triangle Park, North Carolina, prime contractor of the U S Army Materiel Command. Technical guidance and coordination were provided by an Ad Hoc Working Group representing the AMC Commodity Commands and agencies.

The Engineering Design Handbooks fall into two basic categories, those approved for release and sale, and those classified for security reasons. The U S Army Materiel Command policy is to release these Engineering Design Handbooks in accordance with current DoD Directive 7230.7, dated 18 September 1973. All unclassified Handbooks can be obtained from the National Technical Information Service (NTIS). Prodedures for acquiring these Handbooks follow:

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CHAPTER 1
INTRODUCTION

This chapter defines maintenance engineering and discusses the concepts, philosophies, and practices it applies throughout the life cycle of a materiel acquisition program. The relationship of maintenance engineering to maintenance is described. Maintenance engineering objectives are listed, and activities contributing to their attainment are outlined. Design disciplines and support elements interfacing with maintenance engineering are identified, and the techniques used to coordinate design and support element activities are presented.

1-1 WHAT IS MAINTENANCE ENGINEERING?

Maintenance engineering is a distinct discipline established as one of the principal activities within the maintenance organizational structure of each military service and within most industries that produce products requiring maintenance. The Department of Defense defines maintenance engineering as "that activity of equipment maintenance which develops concepts, criteria and technical requirements during the conceptual and acquisition phases to be applied and maintained in a current status during the operational phase to assure timely, adequate and economic maintenance support of weapons and equipments" (Ref. 1). The remainder of this paragraph will interpret this definition by elaborating on the specified functions and giving an overview of how they are accomplished.

The major maintenance engineering contributions to a materiel program are to insure that the materiel is designed for ease and economy of support, to define and develop an adequate and economic maintenance support subsystem that will be available when the materiel is deployed, and to monitor and improve the subsystem until the materiel is removed from the inventory. Design for ease and economy of support is obtained by determining optimum levels of materiel reliability, maintainability, human factors, safety, and transportability design features, and transmitting these features as requirements to design engineers. Requirement decisions result from a series of maintenance engineering analyses that trade off materiel operational requirements, acquisition costs, and support costs.

The support subsystem is comprised of support resources such as trained personnel, repair parts, and Technical Manuals required to support the materiel after it is deployed. Maintenance engineering develops the basis for the subsystem by a series of maintenance engineering analyses that identify and refine the requirements for each type of support resource. The requirements specify where, when, how, why, with what, and by whom the necessary actions will be taken to retain equipment in or restore it to a serviceable condition. After materiel deployment, these requirements are modified when analysis of available data shows that improvements in maintenance economy and efficiency are feasible.

To accomplish its mission, maintenance engineering conducts two closely related types of planning: one involves planning the support of materiel; the other involves planning for the acquisition of resources to provide the planned support. The first type of planning is accomplished almost solely by maintenance engineering, and is constrained by operational requirements and materiel design. The other planning is accomplished mainly by organizational support elements in consonance with the maintenance engineering analyses, planning, and resulting requirements. Maintenance engineering consolidates all of the planning decisions into materiel support plans, which become part of a total plan for materiel acquisition and deployment.

Maintenance engineering is a dynamic function. The depth of analyses and consequently the depth of detail in the generated plans and requirements are limited by available design and support data. These data are quite gross at the start of most materiel programs, but become increasingly detailed as time progresses. As a result of iterative analyses, maintenance 'engineering plans and design and support requirements are progressively refined. An exception to the foregoing occurs when a materiel program involves the procurement and deployment of off-the-shelf equipment. In this case, complete design data and operational requirements are immediately available, and the development and refinement of plans and support requirements can be accomplished with relatively few iterations of the maintenance analysis process.

It is important to note that maintenance engineering is responsible for generating design and support requirements, for monitoring actions taken to satisfy the requirements, and for judging the adequacy of the actions, but usually is not responsible for taking the actions. For example, maintenance engineering might impose a materiel design requirement for modular packaging, and a support requirement for removal and replacement of modules at the organizational level of maintenance. The latter requirement is then refined into detailed requirements specifying the personnel skills and quantities and repair parts required and describing how the maintenance action will be performed. The design requirements are submitted to design personnel, and the support requirements are submitted to personnel in the personnel training, repair parts, and technical publications support organizations. In both cases, maintenance engineering takes no action to actually satisfy the requirements, but is responsible for insuring that the requirements are satisfied according to schedules that are compatible with deployment schedules.

An analogy can be drawn between system engineering and hardware development, and maintenance engineering and support subsystem development. The system engineer establishes the overall design concept, performance requirements, and interfaces among functional system elements. Detailed design (system electronics or hydraulics, for example) is performed by other disciplines. Similarly, the maintenance engineer establishes the overall support concept, performance requirements for the support resources, and interface requirements. Detailed design of the resources is accomplished by other disciplines. Thus, the maintenance engineer is the system engineer for the maintenance support subsystem.

Maintenance engineering is a technical analysis and planning function rather than a function that physically performs maintenance. The end products of the analysis and planning are mission-ready end item weapons and equipment. The maintenance engineering effort, therefore, is oriented toward end items as systems, as contrasted with considering end items that are associated with more than one system as a homogeneous group (Ref. 1).

Maintenance engineering participates throughout the life cycle of a materiel acquisition program, and all significant decisions and findings are based on maintenance engineering analyses. During the conceptual phase for new materiel, historical maintenance data and support concepts are researched for use in developing materiel technical requirements (Ref. 1). Maintenance analyses are then conducted to develop a broad general plan for logistic support that identifies anticipated critical issues of supportability, the anticipated materiel logistic environment, goals for life cycle support costs, and recommended maintainability and reliability parameters. This plan becomes part of an overall plan for acquiring the materiel (Ref. 2). Although all program decisions are important, the initial support decisions are of particular significance, since, barring program reorientation, all subsequent support decisions are refinements of the initial decisions.

During the next phase, which involves definition and validation of the selected approach, studies are conducted, prototype hardware may be designed, and final reports, which include plans for materiel development, are prepared. Maintenance engineering participates in the support aspects of all these activities. It provides support guidance, conducts support tradeoffs, provides information for reliability and maintainability studies, and updates and expands the maintenance analyses, which are still generalized, but of increasing depth, since functional design information is available to augment historical data. Mathematical and simulation support models are used during this and subsequent phases. The results of maintenance engineering activity are a firm system maintenance concept, support plans, and maintenance related specifications.

Maintenance engineering activity starts to peak as materiel is designed, developed, and tested. Previously described activities are continued, and, as soon as preliminary engineering drawings are available, formal documentation of maintenance engineering analysis data is instituted. This analysis is continuously updated as the design evolves and becomes more detailed. All design changes are evaluated to determine the impact on support parameters, and in turn, maintenance analysis reveals deficiencies that require design changes. Although many design changes are anticipated prior to production, early analysis is necessary in order to provide early planning data for long-lead support resources. The early maintenance analysis should be conducted in accordance with the same procedure as that used later in the program, and the data generated should be in the same format, to the extent possible, and limited only by the degree of design detail available. Requirements for the complete support subsystem are refined, and support resources are developed. Production configurations of operating materiel and support equipment and the resources of appropriate support elements are tested as a system to determine the adequacy of the planned support. These maintenance engineering activities will result in final materiel support plans and an operating maintenance analysis data system.

As production is accelerated, maintenance engineering activity declines from its peak. Design change impacts are analyzed; compatibility is maintained between the design changes, the data system, and the materiel support plans; and the acquisition of support resources is monitored. Additionally, a plan is prepared for modifying the materiel if modifications are required after it is deployed.

During deployment, maintenance engineering evaluates and analyzes the maintenance and operating experience of deployed materiel. The efficiency and effectiveness of support are determined, in large part, by comparing field data with the maintenance analysis data that were previously compiled. Problems are solved by in-depth maintenance analyses. In some cases, the solution will be to modify the maintenance support plans. In other cases, both hardware changes and support plan modifications will be required. As the materiel life cycle approaches its conclusion and sufficient data relating to the future force structure become available, maintenance engineering prescribes technical criteria regarding the final disposal of materiel, and a plan is prepared for removing the materiel from the inventory. Preparation and implementation of the plan are not maintenance engineering responsibilities.

Maintenance engineering depends heavily upon historical maintenance data. It is virtually the only type of data upon which to base decisions during the early part of a materiel program. Subsequently, design data upon which to base technical decisions become available, but historical data remain as a valuable source of ideas and a tool with which to test the validity of analytical determinations. Analysis of past experience reveals which characteristics have or have not proved satisfactory on existing items. Such analysis discloses major downtime contributors, indicates high failure rate items, identifies design features that benefit support, identifies prime contributors to high cost, indicates maintenance man-hour requirements, helps identify trouble spots, and provides parameters for analyses.

Without the benefit of the operational and support history of previous systems, the maintenance engineer cannot perform his function efficiently and effectively on a new system. This highlights an easily overlooked fact: data acquired and analyzed after deployment of a system benefit not only the system itself, but also future systems.

Materiel support resource requirements vary with design changes, and are termed support parameters when considered in this light. Similarly, design features that impact support requirements are termed maintenance parameters. One of the most important maintenance engineering functions is to influence the maintenance parameters in order to reduce the cost of the support parameters by an amount greater than any increase accruing to materiel acquisition costs as a result of design changes. For example, the design of equipment with discard-at-failure modules will normally improve materiel availability and reduce the costs of the personnel, training, and publication support parameters. On the other hand, repair part costs and basic hardware costs will probably increase. If the total of the reduced costs exceeds the total of the increased costs, on a life cycle basis, discard-at-failure modules comprise a desirable maintenance parameter. A proper course of action cannot be selected without a detailed tradeoff. Par. 1-3 discusses maintenance engineering objectives, and it will be noted that many of these objectives can be attained by properly influencing design. It must be emphasized, however, that each item of materiel and its operational requirements pose a unique problem, and maintenance parameters suitable for one combination might be undesirable for another.

1-2 INTERFACE BETWEEN MAINTENANCE ENGINEERING AND MAINTENANCE

Maintenance engineering and maintenance are two distinct disciplines with well-defined interfaces. Maintenance engineering assists in the acquisition of resources required for maintenance and provides policies and plans for the utilization of the resources in accomplishing maintenance. Maintenance activities make use of the resources in physically performing those actions and tasks attendant on the equipment maintenance function for servicing, repair, test, overhaul, modification, calibration, modernization, conversion, etc. (Ref. **1**).

Maintenance engineering activities begin in the conceptual phase of a materiel program and continue throughout its life cycle. Maintenance activities begin at the start of the deployment phase and continue until disposal. During the deployment phase, when the two activities are concurrent, maintenance personnel document maintenance experience in formats prescribed by applicable directives. Maintenance engineering analyzes these data and may establish requirements for equipment modifications and modified maintenance policies or plans (Ref: **3**).

Maintenance engineering defines, integrates, and evaluates the total support subsystem. Any changes in system technical requirements or in the support plan that are subjected to a maintenance analysis invariably will impact upon more than one support element. Maintenance is performed at levels identified as organizational, field, and depot, each of which is devoted to the maintenance of system components specified by maintenance engineering. Maintenance personnel are not responsible for considering the total support subsystem, which would, of course, duplicate maintenance engineering functions.

Although maintenance engineering and maintenance have the same objective, i.e., mission ready equipment at lowest cost, the environments in which they function are significantly different. Maintenance engineering is an analytical function and, as such, is methodical and deliberate. On the other hand, maintenance is a function which, particularly in combat, must be performed under adverse circumstances and great stress. At such a time, its one goal is to rapidly restore the equipment to an operational status with the resources at hand. Whether the task can be performed rapidly and economically under those circumstances depends in large part upon how well past maintenance engineering decisions reflect an understanding of maintenance problems generated by the operational environment.

1-3 MAINTENANCE ENGINEERING OBJECTIVES

The fundamental objectives of maintenance engineering are to insure that new materiel is designed for ease of maintenance and that an adequate economic support subsystem is provided in a timely manner. These objectives must be attained concurrently to reach an optimum balance between design and support. It is possible to provide an optimum support subsystem for a poorly conceived design, but this subsystem would represent failure in the achievement of the maintenance engineering design objective, and consequently would not be comparable economically to a support subsystem for well-designed materiel. The design and support objectives are inseparable.

The fundamental objectives may be attained through identification and attainment of a series of contributing objectives (Ref. **4**). Each objective is very important, but is termed contributing because its accomplishment merely contributes to accomplishment of the fundamental objectives rather than their complete accomplishment. The contributing objectives are:

a. Reduce the amount and frequency of maintenance.

b. Improve maintenance operations.

c. Reduce the amount of supply support.

d. Establish optimum frequency and extent of preventive maintenance to be performed.

e. Minimize the effect of complexity.

f. Reduce the maintenance skills required.

g. Reduce the volume and improve the quality of maintenance publications.

h. Provide maintenance information and improve maintenance educational programs.

i. Improve the maintenance organization.

j. Improve and insure maximum utilization of maintenance facilities.

The actions required for attainment of the contributing objectives (Ref. 4), and hence the fundamental objectives, must start when materiel is being conceived and must continue until it is removed from the inventory. The actions impact design, and the structure and application of support resources. Some of the actions, by strict definition, do not fall within maintenance engineering functions, but since they impact adequacy and economy of support, maintenance engineering must provide leadership in insuring that they are accomplished. Each contributing objective and some of the more important actions supporting its attainment follow. Wherever appropriate, the phrase "when cost-effective" should be considered implicit in the action statements. It will be noted that some of the actions support the attainment of more than one objective.

a. Reduce the amount and frequency of maintenance:

(1) Establish a support concept and qualitative design requirements when materiel is being conceived.

(2) Establish quantitative maintainability and reliability design features early enough to permit their incorporation into the materiel development program.

(3) When feasible, stress modular packaging, quick go/no-go diagnostics, prognostics, and accessibility.

(4) Make maximum use of test and maintenance data in establishing and evaluating support element resources.

(5) Accomplish a teardown of materiel prior to preparation of final maintenance allocation charts and initial provisioning.

(6) Obtain and analyze maintenance, performance, and failure data from the field, and correct discrepancies.

(7) Perform no unnecessary maintenance.

(8) Carefully establish inspection procedures and criteria by which to determine repair eligibility of materiel.

(9) Publish lists of materiel to be cannibalized or salvaged when it becomes unserviceable.

b. Improve maintenance operations:

(1) Define and apply the best of current management and maintenance techniques.

(2) Research industry practices, participate in symposia, and review trade publications.

(3) When possible, establish standard commercial-type test, measurement, and diagnostic/prognostic equipment, tools, and handling equipment for use in maintenance shops.

(4) Develop uniform criteria and procedures for computing maintenance workloads.

(5) Establish a file of reference data on all work operations, including time and overhaul standards, layouts, tool and equipment requirements, and related information, to expedite planning and accomplishment of recurring operations.

(6) Develop and apply simplified internal budgeting techniques to control costs in maintenance shops.

c. Reduce the amount of supply support:

(1) Reduce the number of varieties of equipment, components, and repair parts by standardization, eliminating nonessential items, phasing out obsolete materiel, emphasizing geographical standardization, and, when feasible, using restrictive procurement to augment existing inventories with identical items.

(2) Screen repair parts lists and eliminate duplications.

(3) Use cannibalization as a source of low mortality repair parts and for repair parts not type classified as standard during the latter part of the materiel life cycle.

(4) Maintain current, worldwide inventories of materiel requiring repair parts support.

(5) Develop and publish data identifying where repair parts are used, by make, model, and serial number, if necessary, of end items, assemblies, and components.

(6) Determine and publish data pertaining to repair parts interchangeability.

(7) Periodically review authorizations of expendable supplies and assure compatibility between current authorizations and requirements.

d. Reduce the frequency and extent of preventive maintenance to be performed:

(1) Establish design requirements such as self-adjusting assemblies, self-lubricating bearings, and corrosion-resistant finishes.

(2) Apply diagnostic/prognostic equipment and techniques to eliminate teardown inspections for determining required maintenance.

(3) Establish realistic preventive maintenance intervals based initially upon historical and design data, and adjust the intervals when field experience data become available.

(4) Insure that current preventive maintenance checklists are in the hands of the user.

e. Minimize the effect of complexity:

(1) Design materiel for maximum practical reliability and maintainability.

(2) Design materiel to permit accomplishment of organizational maintenance by easy removal and replacement of modules or assemblies.

(3) Design to provide with the maximum practical number of discard-at-failure modules.

(4) Provide for diagnostics/prognostics by built-in test equipment (BITE) and automatic test equipment **(ATE)** that is easy to operate and interpret.

(5) Accomplish maintenance by replacement of piece parts as a last resort and only at the depot level.

(6) Provide depots with automatic test equipment, and minimize depot requirements for manual troubleshooting.

f. Reduce the maintenance skills required:

(1) Establish, during the conceptual **phase,** an optimum support concept and qualitative design requirements that are compatible with materiel mission requirements.

(2) Establish quantitative maintainability and reliability design features early enough to permit their incorporation into the materiel development program.

(3) When practical, stress simple go/no-go diagnostics and discard-at-failure modules.

(4) Establish design features that eliminate or minimize the need for maintenance.

g. Reduce the volume and improve the quality of maintenance publications:

(1) Use the most advanced and proven military, educational, and commercial techniques for the presentation of material.

(2) When such presentation is effective, present information with combinations of microfilm and taped aural narration.

(3) Make maximum use of illustrations, charts, and tables.

(4) Periodically review maintenance. publications to assure currency.

(5) Critically review maintenance engineering analysis data provided to equipment publications personnel as the basis for manuals.

(6) Conduct careful validation and verification programs for maintenance publications.

(7) Stress adherence to standard definitions and symbols.

(8) Make maximum use of manufacturers' manuals.

h. Provide maintenance information and improve maintenance educational programs:

(1) Establish and maintain a program for dissemination of digested maintenance information of general value to maintenance personnel.

(2) Use available communication media, including military and commercial publications and presentations to military and civilian personnel, to stress the importance **of** maintenance.

(3) Insure that key management personnel, both directly and indirectly associated with maintenance, are adequately indoctrinated with the objectives and importance of maintenance engineering and maintenance by attending appropriate schools as a part of their career development program.

(4) Insure that agencies involved in the maintenance indoctrination of personnel use current material.

(5) Conduct on-the-job maintenance training to augment formal training courses.

i. Improve the maintenance organization:

(1) Place maintenance activities in a position in the organizational structure which provides for authority commensurate with the continuously increasing scope and magnitude of their responsibilities.

(2) Periodically evaluate the personnel and equipment resources assigned to maintenance organizations by determining workloads and resource utilization rates, and make appropriate changes.

(3) Develop and apply improved standards for determining the maintenance resources required to accomplish actual maintenance workloads and similar standards for accurately predicting maintenance workloads that will be generated by new materiel.

(4) Monitor depot maintenance operations, and, when appropriate, insure that successful innovative management procedures and techniques proven at one depot become standard for all depots.

j. Improve and insure maximum utilization of maintenance facilities:

(1) Continuously survey existing Army depot maintenance facilities for essentiality and maximum utilization.

(2) Identify and segregate excess costs resulting from underutilized capabilities of depot maintenance shops, and take appropriate action.

(3) Schedule the total depot maintenance workload into the minimum number of depot maintenance facilities that can efficiently and economically accomplish the work with one-shift operations.

(4) Combine maintenance functions and allied trade shops, and use cross-servicing agreements with other services when economical and practical.

(5) Reduce the variety of facilities, special tools, and test, measurement, and diagnostic equipment by standardization, eliminating obsolete and nonstandard supply items, establishing uniform maintenance procedures and, shop layouts, and conducting effective maintenance engineering activities during the development of special tools and test, measurement, and diagnostic equipment.

1-4 INTERFACE AMONG MAINTENANCE ENGINEERING ELEMENTS AND RELATED DISCIPLINES

Maintenance engineering is the interface between system design and system support. It influences design by levying requirements on the design disciplines of reliability, maintainability, human factors, safety, and transportability. It controls the design of system support since it is the sole activity that establishes resource requirements that must be satisfied by the support subsystem. The requirements are further refined and the resources are developed and acquired by organizational entities called support elements, which are established for support equipment, repair parts and support, equipment publications, personnel and training, facilities, supply and maintenance technical assistance, contract maintenance, and transportation and packaging.

Fig. 1-1 is a chart of maintenance engineering interfaces with these elements. The focal point of the chart contains the three inseparable maintenance engineering elements—analysis, planning, and documentation. Analysis and planning comprise the systematic process by which maintenance engineering considers all factors bearing on timely and economic support, and reaches a decision. Documentation is a systematic recording of the analysis process and of the decisions reached. Analysis, planning, and documentation are accomplished within a broad spectrum of formality. At one extreme, analysis and planning can involve the solution of a current problem by the simple application of historical data and judgment. The companion documentation could be correspondence documenting the solution and giving the rationale, and a milestone in a plan. The middle of the spectrum is represented by analyses involving trade-offs among various support alternatives, reaching a decision, and documenting the trade-offs and the decision. Typical of the other spectrum extreme are formal analysis, planning, and documentation involving detailed examination of system

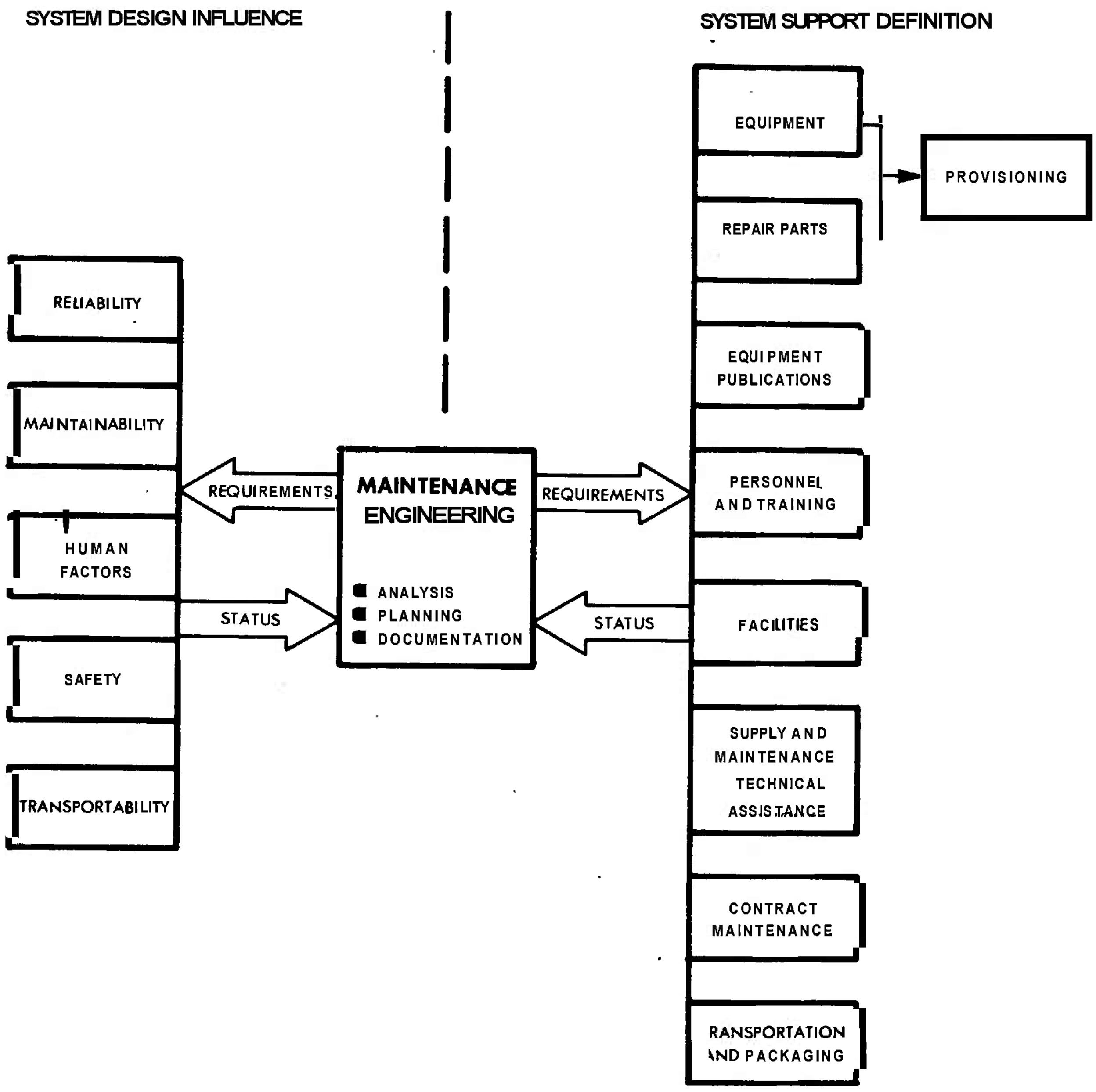


Figure 1-1. Maintenance Engineering Interfaces

materiel to determine support requirements and other maintenance-relevant data, and recording the results in a prescribed format.

The activities (except provisioning) shown in Fig. 1-1 apply to all materiel program phases. Maintenance engineering starts influencing design and defining support requirements in the conceptual phase and continues until disposal. At any point during the program phases, maintenance engineering is aware of the status of design, and the status of the support subsystem. If design were frozen at any point, subsequent maintenance engineering effort would be devoted to refinement of the support subsystem to the degree permitted by the depth of design information. This situation rarely occurs. Design is constantly evolving, even during deployment, as is the support subsystem. As a result, maintenance engineering is continuously receiving design and support status information, performing and documenting analyses, updating plans, and issuing requirements to the design and support functional elements. Maintenance engineering design requirements may not always be completely satisfied because of conflicts with system constraints such as allotted time, performance, size, weight, and available funds. Support requirements are essentially directive in nature, and will be satisfied.

The interfaces among maintenance engineering and the related disciplines can best be described by briefly discussing the contribution of each discipline to support and the type of information that flows between maintenance engineering and the disciplines. The design disciplines will be discussed first, in the order in which they are shown in Fig. 1-1.

Reliability is a characteristic of design that can be expressed briefly as the probability that equipment will perform without failure for a specified time under stated conditions. An analogous definition for maintainability is the probability that an item can be repaired in a specified time under stated conditions. These two design characteristics are very important. They combine to produce availability, which is the probability that materiel will be available for use, when required, under stated conditions. They are also the largest generator of support resource requirements, since failures resulting from unreliability generate the corrective maintenance workload, and the level of maintainability determines how economically the maintenance can be accomplished.

The leverage reliability exerts on the support elements can be appreciated by observing that an item that will function throughout its intended life cycle with no failures requires no maintenance corrective support other than the end items required to replace items lost in combat or otherwise destroyed. It would not be logical to plan for the repair of such equipment. Unfortunately, complex systems with 100 percent reliability are technically or economically impossible to produce, and therefore the maintenance support must be planned for military materiel. Maintenance engineering participates in the establishment of initial reliability requirements. Major considerations are operational requirements, historical data, reliability state of the art, support resource requirements, and materiel acquisition costs. As the program progresses, the reliability requirements are refined whenever it can be demonstrated that operational requirements can be satisfied with reduced life cycle costs. Reliability analyses continuously provide maintenance engineering with predicted reliability or observed reliability, depending upon the materiel program phase.

Predicted reliability data tend to be optimistic when compared to failures that actually occur when materiel is in the hands of the user, because reliability engineers normally deal with inherent reliability—the reliability of the paper design—rather than with reliability of the fielded materiel. Inherent reliability does not account for failures that might result from activities such as manufacturing, acceptance tests, user maintenance activities, and operator errors. Maintenance engineering ascertains how reliability data were derived and, when appropriate, modifies the data with field experience and maintenance engineering judgment.

The objective of maintainability is to design equipment that will satisfy operational availability requirements and can be maintained easily and economically. In relation to support, the term "easily" implies low personnel skills, simple diagnostic procedures, and minimum times to remove, replace, and test the failed, replaceable unit. The term "economically" implies accomplishment of the maintenance at lowest life cycle cost. Maintainability and maintenance engineering objectives with regard to ease and economy of maintenance are the same. Maintenance engineering provides general requirements to maintainability by means of the maintenance concept, assists in the interpretation of the concept and in the conduct of design and support trade-offs, and transmits specific requirements as they become available from analysis. Maintainability determines design features such as equipment packaging and diagnostics that economically satisfy both operational requirements and the maintenance concept and incorporates the features into materiel design. Design maintenance characteristics and predicted or observed repair times are transmitted to maintenance engineering.

Human factors and safety are disciplines closely related to each other, and to maintainability. The objective of human factors is to design both operational and support equipment so that its use and maintenance are compatible with human capabilities. The objective of safety is to design the same equipment so that it can be operated and maintained safely. Maintenance engineering requirements for these disciplines are based on historical data, design analysis, and observation of activities involving the operation and maintenance of hardware. The disciplines transmit design information and safety procedures to maintenance engineering.

Transportability, in its broadest sense, is a design characteristic that establishes the transportation, handling, and packaging requirements for equipment. Some transportability features might be dictated by special operational requirements—such as a capability for equipment to be delivered by parachute. Others—such as compatibility with standard transportation and handling equipment, adequate tiedown and lift points, and compatibility with standard packaging and preservation techniques—are established by maintenance engineering. Materiel design is monitored by maintenance engineering to insure that transportability requirements are satisfied.

Maintenance engineering derives quantitative and qualitative resource requirements for each of the support elements by analyzing available data—including design information, historical data, and operational requirements—as they apply to the current maintenance concept. The requirements include delivery schedules that must be satisfied. The support functional elements feed back detailed plans for satisfying the requirements, and maintenance engineering develops a materiel support plan that defines how each type of resource will be used in logistic support and how it will be obtained. Typical products of each support element, other than a plan, and the nature of the requirements received by the element from maintenance engineering are discussed in the paragraphs that follow.

Support equipment includes test, measurement, and diagnostic equipment, handling equipment, tools, calibration equipment, and training equipment. Maintenance engineering transmits requirements to the support equipment element for both new and standard support equipment. The new equipment undergoes a design cycle identical to that of operational equipment, and maintenance engineering influences the design as previously described. Use locations and quantities for all support equipment are refined, and requirements and supporting data for provisioning the equipment are transmitted to the support equipment element. Maintenance engineering plans the support of support equipment in the same manner that it plans the support of operational equipment.

Repair parts and support include repair parts and maintenance floats. Maintenance engineering identifies all requirements for repair parts and maintenance floats, and generates other data required to provision the items. Requirements and documentation are transmitted to the repair parts and support functional element for satisfaction of the requirements.

After receiving maintenance engineering requirements, personnel from the support equipment and repair parts and support functions participate in provisioning activity. The provisioning activity has the objective of assuring that support equipment and repair parts will be available in the proper locations, when they are required (Ref. 5). The full provisioning cycle involves documentation, selection, coding, determination of maintenance factors, cataloging, computation, procurement, production, and delivery. Maintenance engineering analysis provides the source data for the first four of these functions. Maintenance engineering generates documentation to support provisioning decisions, seiects items, identifies the source of each item, establishes the lowest level of maintenance authorized to use the item, and provides guidance for the disposition of unserviceable items. Additionally, it provides maintenance factors showing the replacement rate requirement generated by deployed items (Ref. 6). The two support functional elements and other agencies complete the provisioning process based on the maintenance engineering inputs. When the volume of data is large, as is the case in major materiel acquisitions, provisioning is accomplished with the assistance of automatic data processing **(ADP)** equipment.

Equipment publications include Technical Manuals, Technical Bulletins, and depot maintenance work requirements that define the manner in which the operational equipment will be operated and maintained. In addition, the publications include Supply Manuals and manuals pertaining to the maintenance and operation of the support equipment. Maintenance engineering inputs to the equipment publication element include much of the information required for preparation of the necessary documentation. Publication personnel augment the information by drawing and hardware analysis.

The objective of the personnel and training element is to train personnel in the numbers and skills required. Maintenance engineering specifies requirements for the numbers and skills, and provides other information that assists in defining training requirements. The personnel and training element prepares courses of instruction, identifies requirements for training equipment, which are made a part of maintenance engineering requirements to the support equipment element, and accomplishes the instruction.

The facility element exists to satisfy all maintenance and storage facility requirements by either reprogramming the use of existing facilities or constructing new facilities. Maintenance engineering describes the facility requirements in terms of utilization, plans or sketches, utility requirements, and other information required by the facility element to accomplish its function.

Supply and maintenance technical assistance is provided to field commanders to augment their organic supply ar3 maintenance capability. This assistance normally is provided by Army military and civilian personnel, but is sometimes provided by contractor field service personnel. Maintenance engineering establishes supply and maintenance technical assistance requirements based on cost-effectiveness considerations. Sometimes, it is cost-effective to use the assistance during a limited period while an organic capability is being established. However, the assistance frequently is provided throughout the operational phase for complex systems and for low-density systems with materiel quantities that do not justify the establishment of a normal full-range support program.

Contract maintenance is that maintenance of Army materiel performed at the organizational, field, or depot level by a contractor on a one-time or continuing basis. Unlike contractor field service, contract maintenance augments Army maintenance resources such as manpower, facilities, equipment, and tools. **As** in the case of supply and maintenance technical assistance, maintenance engineering bases contract maintenance requirements or? cost-effectiveness considerations.

Transportation and packaging include the activities involved in moving equipment from the production line to the point of use and recycling it between the point of use and appropriate maintenance levels. Specifically, it involves preservation, packaging, packing, transportation, and handling. Maintenance engineering provides the transportation and packaging element with requirements that identify quantities, locations, and schedules, and environmental constraints that impact preservation and packaging. The requirements emphasize nonstandard aspects of equipment that preclude normal transportation by military and commercial carriers, and aspects that necessitate special preservation and packaging techniques. Transportation and packaging may identify requirements for additional handling equipment, in which case the requirements will be transmitted to the support equipment element by maintenance engineering.

REFERENCES

1. DoD Inst. 4151.12, *Policies Governing Maintenance Engineering Within the Department of Defense*, 19 June 1968.
2. AR 70-27, *Development Plan/Development Concept Paper/Program Memorandum*, March 1973.
3. AR 750-1, Army *Materiel Maintenance Concepts and Policies*, May 1972.
4. AMCR 750-6, *Maintenance Engineering Objectives*, 7 August 1963.
5. TM 38-715-1, *Provisioning Techniques*, October 1965.
6. AMCP 750-5, *Objective Determination of Maintenance Factors (Draft)*, June 1974.

BIBLIOGRAPHY

DoD Directive 4100.35-G, *Integrated Logistic Support Planning Guide for DoD Systems and Equipment*, October 1968.

TM 38-710, *Integrated Logistic Support Implementation Guide for DoD Systems and Equipment*, March 1972.

Human Engineering Guide to Equipment Design (Revised Edition), Army, Navy, and Air Force, 1972.

AR 1000-1, *Basic Policies for Systems Acquisition by the Department of the Army*, 30 June 1972.

DA LOI, *Letter of Instructions (LOI) for Implementing the New Materiel Acquisition Guidelines*, 23 August 1972.

MIL-HDBK-758, *Human Factors Engineering Design for Army Materiel*.

CHAPTER 2
MAINTENANCE ENGINEERING EFFORT THROUGHOUT THE LIFE CYCLE

This chapter elaborates on the materiel life cycle concept and defines the objectives of each phase. The tools and techniques available to maintenance engineering to insure timely availability of an optimum combination of materiel and support resources are described. **Army** *and contractor plans that provide the basis for all life cycle support activities are discussed.*

2-1 INTRODUCTION

The time frame encompassing all activities associated with a materiel program from conception through disposal is called its life cycle. For management purposes, the life cycle is divided into intervals of time called phases, and each is assigned specific objectives. Phase durations are established by the highest management levels in the Department of Defense and the Army, and vary depending upon technical, economic, and foreign threat factors. These management levels also review progress at specified phase points to determine whether or not subsequent activities should be continued.

Appropriate agencies and disciplines are assigned responsibilities for accomplishing specific functions within each phase. For example, maintenance engineering is responsible for preparing a support concept in the first life cycle phase. These responsibilities are assigned by formal directives. The assignments, coupled with the time frames established for the phases, provide the responsible parties with the information required to plan for the accomplishment of their assigned functions, and provide management with a basis for evaluating progress.

Life cycle phases are designated with descriptive names, which in the past have undergone relatively frequent minor changes. The descriptions of some specific functions have also changed, particularly with regard to the designations of the documentation that must be prepared during the phases. However, the fundamental requirement to prepare documentation remains. When viewed in this light, it may be stated that fundamental functions, including fundamental maintenance engineering functions, have remained unchanged.

In anticipation of future designation changes for both phases and specific functions, this chapter will emphasize the fundamental maintenance engineering functions and will introduce specific phase and functional designations only to the degree required to provide continuity. When these requirements occur, designations current during the preparation of this handbook will be used.

Fig. 2-1 shows the life cycle phases, in the sequence in which they occur during acquisition and deployment of complex materiel, and important decision milestones. During the conceptual and validation phases, program activity is limited to the phase in progress. During portions of the other phases, program activity typically occurs in more than one phase. Phase durations and the durations of phase overlaps are unique to each materiel program (Ref. 1).

Maintenance engineering participates in all of the life cycle phases. Summary statements of phase objectives and some of the most important maintenance engineering activities follow:

a. Conceptual Phase. The objective of this phase is to select a materiel concept and a companion support concept that best satisfy established operational requirements. Selection is based on but not limited to technical, cost, political, world environment, and schedule considerations. Maintenance engineering first provides historical data that assist in selection of the materiel approach that best satisfies the requirements. Subsequently, two functions are performed almost concurrently: (1)the materiel concept is influenced by considerations of economy of support, and **(2)** an economic support concept is developed. Current support resources and concepts as well as new concepts are evaluated for application to the new materiel. Selections and design recommendations are based on analyses, trade-offs, historical data, and judgment. Support plans are prepared and become a part of the materiel documentation package that must receive management approval before the next phase can be initiated.

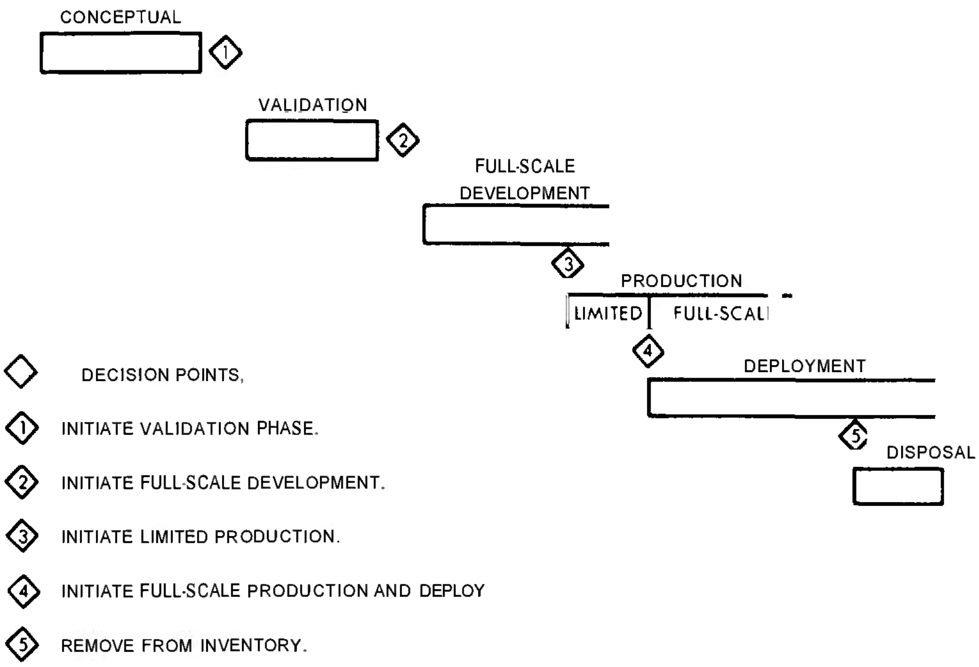


figure 2-1. Materiel Life Cycle Phases

b. Validation Phase. The objective of this phase is to validate and refine conceptual decisions regarding materiel and support. This phase normally is conducted with the assistance of one or more contractors. Maintenance engineering provides support inputs to a request for proposal that solicits contractor proposals to accomplish the validation phase scope of work and assists in evaluating contractor responses. Selected contractors conduct comprehensive studies and may fabricate prototype hardware. The contractors then prepare reports that include materiel and support specifications and proposals for developing and acquiring the materiel and support element resources. Maintenance engineering evaluates the support aspects of the proposals, makes revisions to support planning, and assists in contractor selection. Subsequently, a development contract is negotiated.

c. Full-scale Development Phase. The objectives of this phase are as follows: to prepare a technical data package that can be used to produce operating and support materiel; to develop selected support resources to a degree that they can be used in realistic tests; and to identify and plan for the acquisition of all required support resources. An extensive maintenance engineering analysis effort is initiated. Requirements for design changes are established, and support resource requirements are refined concurrently with progressing design. A preliminary maintenance allocation chart and preliminary technical publications are prepared. Hardware test and demonstration results are reflected in requests for design changes and support requirements. Final plans for the acquisition of support element resources are prepared. Plans should be formulated for verifying the requirement for long lead time support equipment early in the development cycle.

d. Production Phase. The first objective of this phase is to demonstrate with limited production quantities that the materiel produced with production tooling meets planned objectives and is compatible with planned support. Subsequently, full-scale production is initiated, and planned quantities of operating and support materiel and support resources are manufactured or otherwise acquired. Maintenance engineering assists in evaluating test results during limited production. Throughout production, compatibility between design and support is maintained, and the acquisition of support resources is monitored.

e. Deployment Phase. The objectives of this phase are to deploy, operate, and support the materiel. Maintenance engineering receives and analyzes operational performance and support data, recommends design and support changes, and evaluates design changes recommended by other agencies for their impact on support. Support plans, policy, doctrine, and the maintenance analysis data system are updated as required.

f. Disposal Phase. The objective of this phase is to remove materiel from the inventory. Materiel can become obsolete due to improved capabilities of potential enemies, as a result of technological advances that make possible the development of more economical materiel with improved performance characteristics, or more likely, due to a combination of the two factors. Maintenance engineering prepares and provides technical criteria to be used in accomplishing the disposal phase.

Each of these phases is treated in detail in the paragraphs that follow.

2-2 CONCEPTUAL PHASE

The objective of the conceptual phase is to develop and select the best materiel approach that will satisfy an established requirement and to demonstrate the feasibility of the approach from a technical, cost, and schedule standpoint. The conceptual effort is characterized by the generation of materiel design data and utilization plans in sufficient detail to allow gross life cycle cost analyses and the definition of baseline operational and support concepts. The effort encompasses preparation of a development plan that includes a description of the materiel to be developed, a plan for conducting the validation phase, and the support plans. At the conclusion of the conceptual phase, a management review is conducted to insure that the necessary preliminary work has been accomplished and that threat and operational analyses, trade-off and cost and mission effectiveness studies, and the technological state of the art provide a firm foundation for proceeding.

Maintenance engineering is responsible for the accomplishment of all activities directly related to support, and for the maintenance of interfaces with disciplines that impact support. Other disciplines have analogous functions with regard to their responsibilities, and all management levels have a requirement to track progress. Procedural models have been developed to assist all activities in accomplishing their functions properly and on time. Among other functions, these models dictate that maintenance engineering trade-offs and analyses of operational and support parameters be conducted, and that certain support plans be prepared.

Procedural models present the time-phased activities required of all agencies involved in a materiel acquisition program, ranging from management decisions to activities of disciplines such as maintenance engineering, reliability, and maintainability. The models also provide guidance pertaining to methods, coordination and interface requirements, and the destination of the products of the activities. In effect, procedural models are complex functional flow diagrams that specify how materiel will be conceived, fielded, and supported.

Materiel operational parameters are the characteristics that equipment must have in order to satisfy operational requirements; for example, a capability to operate in Arctic regions. Maintenance parameters are the characteristics of materiel that impact maintenance requirements; for example, maintainability features. Maintenance engineering determines the support impact of operational parameters and, by analyses and trade-offs, establishes maintenance parameters that result in satisfaction of the operational parameters at least cost.

Support planning is designed to identify, schedule, and control the activities required for timely and adequate support of materiel. These activities pertain to plans, events, and resources necessary for analysis and evaluation of support requirements, and for development, acquisition, and use of support resources. Support planning is based on materiel maintenance characteristics. Support plans are the implementing documents for maintenance decisions. They reflect the current state of proposed maintenance for the system, and establish a baseline for support resource development.

Support plans, in general, describe the maintenance actions that are being considered for the materiel and the projected maintenance and supply capability necessary to accomplish the actions. Specific functional area plans are prepared to provide this capability. Support plans prepared during the conceptual phase comprise a part of the resulting baseline documentation. It is very important that the support plans completely define both objectives and requirements to insure that support receives proper consideration in the validation phase.

2-2.1 PROCEDURAL MODEL

Numerous Army agencies, the Office of the Secretary of Defense, and one or more contractors participate in a major materiel acquisition program. Regulations and directives specify how these programs will be conducted, but it is easy to envision the confusion that could result if each agency planned its own and its interface activities based on its interpretation of the current directives. To circumvent the potential problem, procedural models have been developed that lay out in a timed sequence the activity responsibilities and interfaces of each agency. The models can be simplified and made more useful by emphasizing a major activity—support planning and acquisition, for example—and that is precisely what is done in the case of support procedural models that have been developed and published for each life cycle phase.

At the start of a materiel acquisition program, maintenance engineering should first acquire a current support procedural model, study the model along with pertinent directives, and plan conceptual activities. Fig. 2-2 shows a support procedural model for the conceptual phase developed to an intermediate level of detail.

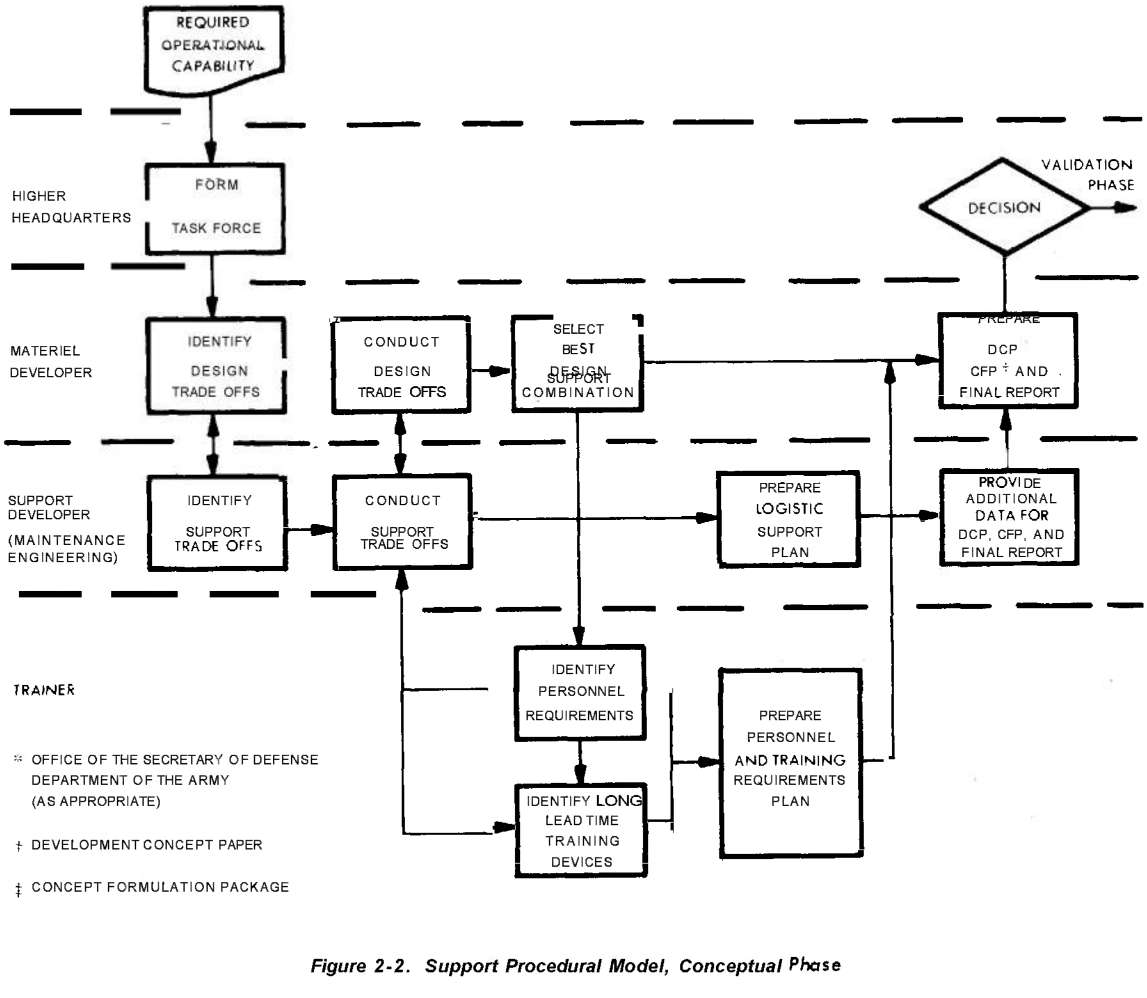


Figure 2-2. Support Procedural Model, Conceptual Phase

This level is most useful for a general model. For a specific situation, each of the activity blocks can be expanded to lower levels, but the value derived from such expansion would be doubtful. A model user should be experienced to a degree that a requirement to identify support trade-offs, for example, need not be backed up with several blocks describing how the requirement is to be accomplished.

The discussion of Fig. **2-2** which follows will result in a description of maintenance engineering activities in the conceptual phase and will show how these activities are guided by a procedural model. The first thing to note is that four separate agencies are directly involved. Two other agencies, indirectly involved, are the combat developer and the user. (These have been omitted in the interest of simplicity.) For a major materiel program, higher headquarters decisions are made by both the Office of the Secretary of Defense and the Department of the Army. The design engineering discipline is the materiel developer, the maintenance engineering discipline is the support developer, and the trainer represents Army training organizations.

Conceptual activity in the model starts with identification of an operational requirement by any Army agency. The requirement is prepared in a prescribed format, and is processed and submitted to higher headquarters for approval. If approved, higher headquarters appoints a task force to prepare the documentation requisite to a decision to proceed to the validation phase. Within the task force are representatives of the activities shown, as well as combat developer and user representatives. Although the task force is dissolved at the end of the conceptual phase, the materiel developer, support developer, and other activities continue to function.

The materiel developer and support developer work together closely. First, each identifies feasible trade-offs within his sphere of responsibility, and then each conducts trade-offs. Note that these activities are interdependent, as are support developer and trainer activities. During this period, maintenance, operational, and support parameters are traded off against life cycle costs and effectiveness. The trade-offs necessitate identifying and costing support element resources required for each approach. Historical data are quite valuable in identifying feasible support approaches and in making the required gross cost estimates.

After the trade-offs, the materiel developer selects the best combination of design and support concepts. The trainer refines the personnel requirements and long lead time training devices required by this approach, and prepares a personnel and training requirement plan. The plan identifies new skills, individual and crew training requirements, training devices, training facilities, and associated schedules. The plan also provides current information concerning numbers and skills of personnel involved in the use, maintenance, and support of the proposed materiel. Training devices that require long development lead times are separately identified. Not shown in the model is the fact that information on personnel requirements derived from the plan is forwarded to the combat developer for his planning purposes.

The support developer refines support requirements for the selected approach and prepares a logistic support plan. The support plan is broad in scope and includes milestones for verifying the status of support development at appropriate points in the materiel life cycle. The plan also includes critical issues of supportability, the anticipated logistic environment in which the materiel is expected to operate, life cycle support cost goals, and recommended maintainability and reliability parameters. The plan is greatly expanded in subsequent life cycle phases.

The support developer generates a considerable quantity of additional data and plans to be included in the documentation output of the conceptual phase. Some of the most significant are inputs to a coordinated test plan involving both testing requirements and a plan for supporting the tests, and inputs to plans and requirements for the validation and subsequent phases. Among these inputs are support management control techniques defining the controls to be used, and maintenance engineering analysis data management requirements.

The training and logistic support plans and other support data are forwarded for inclusion in a development concept paper, a concept formulation package, and a final report. The total task force makes contributions to these documents, but the materiel developer is the major recipient and integrator of support inputs. Eventually, the three documents are forwarded to higher headquarters, and their approval authorizes initiation of the validation phase.

2-2.2 OPERATIONAL AND MAINTENANCE PARAMEYERS

Materiel is acquired to perform specific missions in specific environments. These missions and environments generally are termed operational requirements or operational parameters. Established operational parameters may be satisfied by various combinations of design and support, but they must be satisfied. The support contribution to the attainment of operational parameters also can be a combination of design and support; for example, maintainability features coupled with a maintenance float will contribute to the operational parameter of availability. A function of maintenance engineering is to insure that the design selected to satisfy the basic operational parameters (range or payload, for example), when coupled with maintenance factors and support techniques, will result in materiel that can be effectively and economically supported. This means that operational parameters must be analyzed and their support impact fully understood before useful maintenance engineering work can be accomplished.

2-2.2.1 Operational Parameters

Some of the most significant operational parameters that, must be evaluated are:

a. Mission profiles

b. Operational states

c. Mission time factors

d. Availability requirements

e. Operational environments

f. Deployment plans, including quantities, locations, and schedules.

The first three parameters depict, on a calendar basis, the active and inactive status of the materiel, the time on alert or standby, the mission frequency and duration, and other operational demand periods. Analysis of these data and availability requirements will reveal the periods during which time is available for maintenance actions, the location of the materiel at these times, and the types of maintenance that can be performed within the allotted times.

The geographical and environmental conditions under which the weapon systems are to operate must be subjected to analysis. Materiel deterioration caused by climate and terrain must be taken into account during development of maintenance policies. Geographical deployment affects the ease with which the weapon may be supplied and supported. The working environment affects human performance and requires design and maintenance policies that will optimize maintenance. Finally, deployment plans must be evaluated carefully. Support design requirements and support concepts differ radically for a few units of materiel in a single location versus numerous units deployed on a worldwide basis.

2-2.2.2 Maintenance Parameters

An analysis of the operational parameters will show which maintenance parameters are tentatively acceptable and should be evaluated, and which are unacceptable. In broad terms, maintenance parameters include reliability and maintainability. Some of the more significant maintenance parameters in the latter category are:

a. Fault isolation

b. Mechanical and electrical packaging into modules, assemblies, etc.

c. Accessibility

d. Adjustments

e. Interchangeability

f. Standardization.

These parameters must be grouped for some applications, and may be used singly for others. The first four, as a group, determine mean time to repair, and skill requirements, and with reliability, determine maintenance man-hour requirements. The last two impact support economy. Quantitative statements of maintainability resulting from such groupings are also termed maintenance parameters. Some of the most important of these parameters are:

a. Mean time and maximum time to repair at each level of maintenance operations *b.* Mean and maximum downtime for corrective maintenance

c. Maintenance man-hours per utilization hour—total and by category of maintenance operations

d. Minimum allowable time between scheduled maintenance actions for each category of maintenance operations

e. Mean and minimum time between/before overhaul

f. Maintenance man-hours by skill level/specific maintenance action.

The example that follows demonstrates how maintenance engineering selects maintenance parameters. Suppose that an analysis of operational parameters reveals that the maximum time available to accomplish a certain corrective maintenance action is 30 minutes. An analysis of the proposed design reveals that 40 minutes will be required, with the time about equally distributed between fault location, removal and replacement, and test and checkout. Various combinations of fault isolation methods, packaging, and accessibility that will result in a repair time of 30 minutes are traded off against costs. The best combination is selected, and appropriate design requirements are established. In an actual analysis, the problem normally is not so easily solved because of system interactions, but the principles apply nonetheless.

Established operational and maintenance parameters are made a part of contract specifications, and must be stated in quantitative terms, or in some other manner that permits demonstration of achievement. It would be sufficient to state that like parts will be interchangeable without adjustments. On the other hand, it would not be sufficient to state that good accessibility will be provided. This would have to be defined in terms of numbers and types of fasteners, sizes of access ports, time, and similar terms.

2-2.3 PLANNING TECHNIQUES

To provide for orderly documentation of support requirements within the materiel management spectrum, the Army uses a series of formal documentary plans that provide an interlock of all system documentation by cross-referencing plans with each other and with supporting documentation. Initiated early in the conceptual phase, these plans are the media that flow through management channels at various levels to provide the information on which materiel management actions and decisions can be made. These documents are not static records but continue to recycle through management channels, since they are updated as the materiel is validated, developed, operated, modified, and subsequently phased out (Ref 2).

2-2.3.1 Development Plan

Virtually all of the plans of interest to maintenance engineering are contained in a development plan. The development plan, which is comprised of multiple plans, documents the program decisions, user requirements, and analyses of technical options and life cycle plans for development, production, and support of materiel. The development plan is a document of record maintained to reflect all phases of planning and program execution consistent with direction and policies of the Army. It is the controlling document for the materiel development effort and is appropriately refined and updated throughout the materiel life cycle. The specific content, scope, and level of detail are tailored to the needs of the particular program and its stage of development.

The development plan documents both the technical and administrative plans, and identifies responsibilities, tasks, and time phasing related to the major actions, principal objectives, and major decisions. The plan is comprised of the sections and subsections depicted by the blocks in Figs. 2-3 and 2-4.

2-2.3.2 Plan for Logistic Support

The plan for logistic support (Fig. 2-4) is the primary planning and management tool designed to identify, schedule, and control the action elements required for timely and economical support of materiel. The action elements pertain to plans, events, and resources necessary for the analysis and evaluation of prototype materiel and for the development, acquisition, and use of support resources. The plan identifies reliability and maintainability characteristics and the qualitative and quantitative requirements for the support elements of

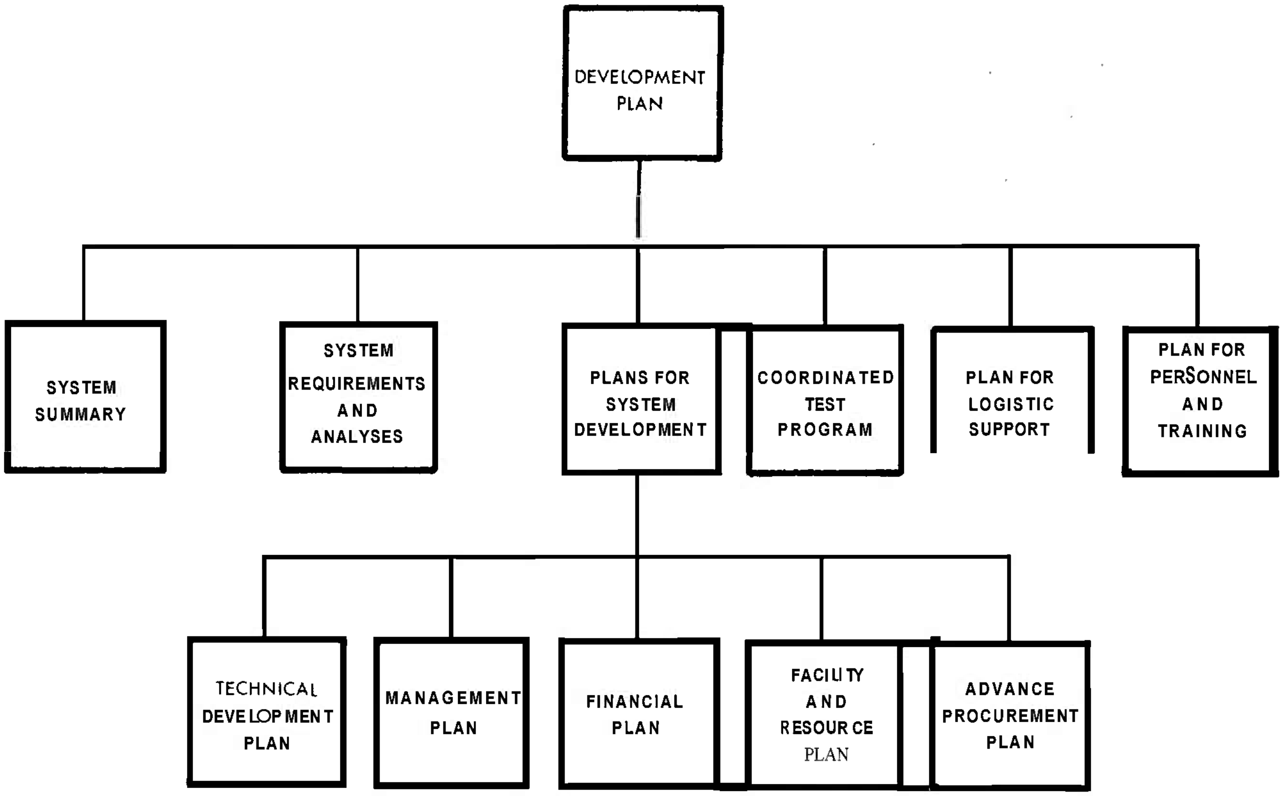


Figure 2-3. Development Plan

materiel, and contains scheduling data and narrative information concerning the planned use and support of the item. The total range and depth of documentation do not spring into being at one time. A basic maintenance concept for a logistic approach to new materiel is conceived during conceptual studies. Such studies provide source data for an. equally basic maintenance plan and support element plans. A brief description of the contents of a plan for logistic support follows for the purpose of demonstrating the types, not the depth, of planning that may emerge from the conceptual effort (Ref. 2).

2-2.3.2.1 Schedule and Basis for Logistic Support Planning

The schedule of logistic support planning (Fig. 2-4) establishes a schedule for support planning events, such as a schedule for developing and refining remaining parts of the total support plan. The basis for logistic support planning briefly states the intended function or application of the materiel, describes its major and secondary end items, and provides data on performance and physical characteristics. Also listed are support data for the materiel, such as nomenclature, stock number, proposed type classification and the agency responsible for logistic support, and operational readiness float information. Included are procurement status, the planned procurement for the immediate future, and the type of funding for test items and quantity procurement.

2-2.3.2.2 Elements of Logistic Support

Elements of logistic support comprise the major portion of the logistic support plan. These elements consist of a maintenance plan, support element plans, and plans for funding and managing the support program.

a. Maintenance Plan. The maintenance plan addresses operational requirements, the

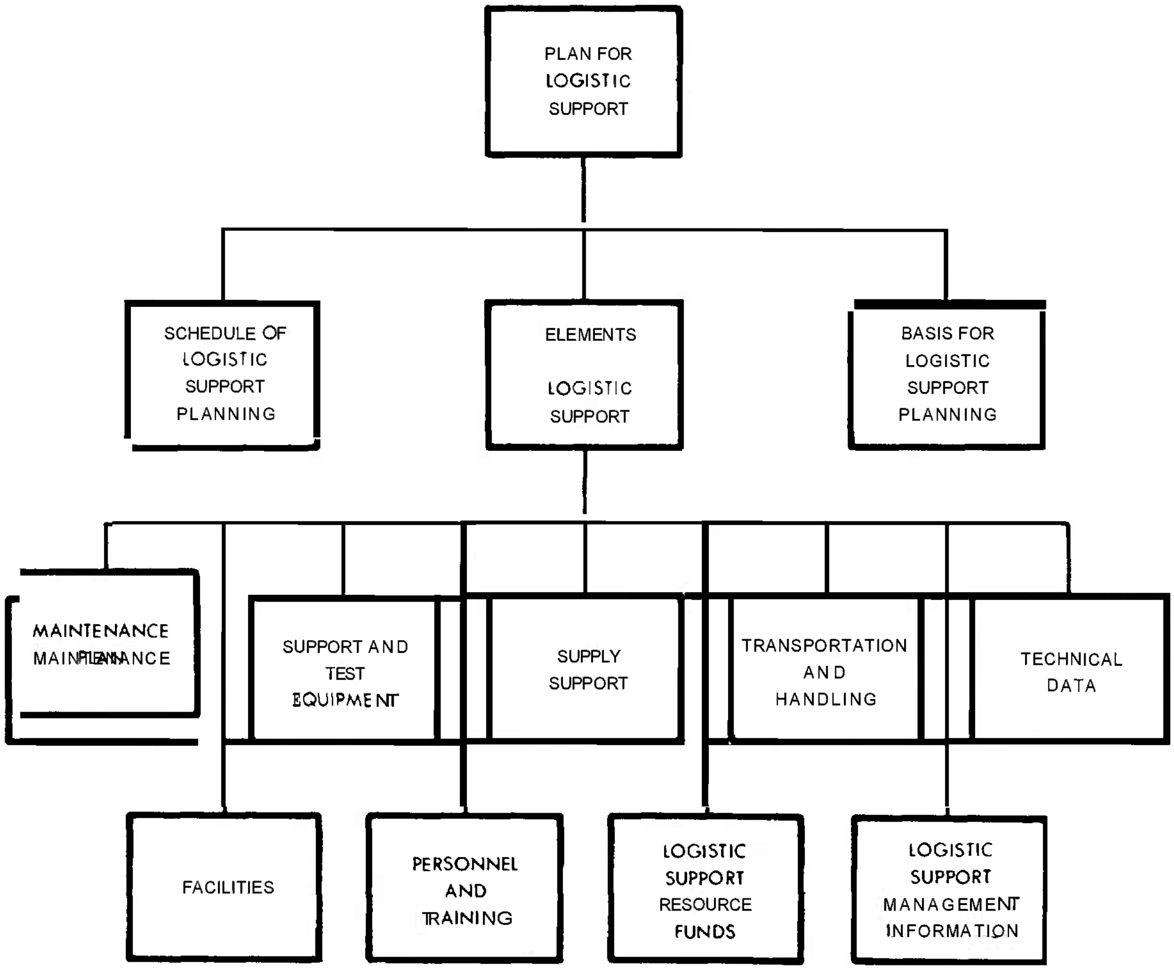


Figure 2-4. Plan for logistic Support

plan for maintenance, and user and support organizations. Operational requirements or parameters—initially established by a required operational capability, expanded by conceptual studies, and restated in a document covering system requirements and analyses (Fig. 2-3)—are included as a background for support planning. The types of operational parameters discussed are identical to those listed in par. **2-2.2.1.** The other major portion of the plan includes the reliability and maintainability parameters (from the technical development plan, Fig. **2-3)** that are considered with the operational parameters in order to select a maintenance plan,. and states decisions reached as follows:

(1) Maintenance categories and repair levels

(2) Packaging concept

(3) Test and checkout concept

(4) Designation of support depot

(5) Maintenance float considerations

(6) Peculiar logistic considerations involving activities such as calibration, storage, transportation, and handling.

Other areas **of** the maintenance plan identify using and support organizations, maintenance test requirements, support plans for the coordinated test program, and a plan for accomplishing physical teardown of the materiel.

Source data for test planning are contained in the coordinated test program plan (Fig. **2-3).**

b. Support and Test Equipment Plan. The support and test equipment plan outlines all requirements for organizational through depot levels for support equipment, including special-purpose vehicles, test equipment, special tools, calibration equipment, and handling equipment. It identifies the level of maintenance to which equipment is allocated, the agency responsible for logistic support, the type classification status, the procurement status, operational readiness float requirements, and the forecast equipment delivery by date and quantity. Operating and support equipment that requires calibration and measurement is specified, and a plan for accomplishing the calibration and measurement is presented. The availability of required support and test equipment is established, or plans for its acquisition are presented.

c. Supply Support Plan. The supply support plan states the programmed action dates for required provisioning schedules, and the date on which the National Inventory Control Point has placed requirements on other responsible agencies for repair parts to support the materiel under development or procurement. The estimated cost of repair parts support for the first year of operation, pertinent data for emergency requisitions, and the identity of any special supply procedures are included. Storage requirements, special requirements for care and preservation and for demilitarization of material (such as disposal of radioactive material), and long lead time repair parts are identified. The procurement status of the long lead time items is shown. The provisioning plan is part of the supply support element; It is the vehicle for scheduling and accomplishing all actions.required to deliver repair parts, tools, test equipment, and support equipment to the user for the initial period of service.

d. Transportation and Handling Plan. The transportation and handling plan identifies materiel transportability characteristics, transportation requirements, and a plan for obtaining transportation resources and satisfying the requirements. Both operating and support materiel are considered. Transportability data such as size, weight, safety, fragility, and security requirements are listed. Typical of the transportation data are required locations, times, and quantities. A plan is shown for the acquisition of the preservation, packaging, and transportation resources to satisfy the preceding requirements, with achievement dates compatible with materiel development milestones.

e. Technical Data Plan. The technical data plan provides for development and distribution of drawings, operating, maintenance, and modification instructions, provisioning and facilities information, specifications, inspection, test, and calibration procedures, instruction cards and equipment placards, special-purpose computer programs, and other forms of audio or visual presentations required to guide personnel in performing operations and support tasks. Army equipment publications, planned or available, are listed. If other than official Army equipment publications are to be used for support of the materiel during tests, both the level of materiel, to be supported and the publication(s) to be used are identified specifically. A list of requirements for equipment operational, historical, and maintenance forms is included.

f. Facility Plan. The facility plan states the area required to accommodate shop supply, maintenance, and storage for all categories of maintenance. Desired area features are defined by descriptions of utility, prime power, humidity, temperature, and dust control requirements. Illustrations or sketches are used to depict special operational and maintenance layouts, and requirements for new or modified depot facilities are explained in general terms. Source data for this plan are contained in the facility and resource plan (Fig. **2-3).**

g. Personnel and Training Plan. The personnel and training plan contains qualitative and quantitative personnel requirements and training information. The plan lists military occupational specialty requirements by number and title for operator, organizational, direct support, general support, and depot maintenance personnel. New-equipment training requirements, which include instruction for in: structor personnel and special training aids or devices, are identified. All requirements for new-equipment introductory letters, introductory teams, and training teams are identified, and the locations of initial training courses for operator and maintenance personnel in all categories of maintenance and training required for test personnel are specified. The plan also identifies requirements for supply and maintenance technical assistance, and presents a plan for satisfying the requirements. Source data for the plan are contained in the plan for personnel and training requirements (Fig. 2-3).

h. Logistic Support Resource Funds **Plan.** The logistic support resource funds plan identifies support funding requirements for each logistic element, each program phase, new requirements, and the allocation and maintenance of existing capabilities. The element also contains a financial plan for support that shows how development and accomplishment of planned logistic support will be funded. Basic data for the support resource funds element are contained in the financial plan (Fig. 2-3).

i. Logistic Support Management Information **Plan.** The logistic support management information plan (Fig. 2-4) defines requirements and responsibilities for the acquisition and use of management data. The plan identifies the planned use of management techniques and documents such as test and demonstration reports and the Army maintenance management system, and assigns responsibilities for acquiring the necessary data at specified times. Attained operational and maintenance parameters are identified as data to be periodically recorded and evaluated to determine progress. The breadth and depth of the maintenance documentation and analysis techniques to be used are defined in detail. Responsibilities for data generation, acquisition, analysis, and dissemination of reports are assigned.

2-3 VALIDATION PHASE

Higher authority approval of conceptual phase documentation results in initiation of the validation phase. This phase can be conducted solely by the Army, or with contractor assistance. The same fundamental effort must be accomplished in either event. A phase objective is to insure that full-scale development is not started until costs, schedules, and performance and support objectives have been carefully prepared and evaluated against one another, and a high probability of successfully accomplishing the development of the materiel can be anticipated. The ultimate goal is achievable performance and support specifications that are responsive to the operational requirements; and are backed by a firm fixed price or full structured incentive-type contract, when full-scale development is to be performed by a contractor.

Contractor assistance normally is used during a major materiel acquisition program. When this approach is selected, the validation phase effort is divided into three distinct intervals. During the first interval, a request for proposal is prepared and contractors are selected. Contractor work is performed during the second interval. During the final interval, contractor reports are evaluated; materiel program plans, including support plans, are updated; the materiel configuration is refined; and a contractor to accomplish full-scale development is selected.

2-3.1 REQUEST FOR PROPOSAL INPUTS

Adequate and effective materiel support planning must be accomplished during validation to insure inclusion of support requirements in the full-scale development contract. For this to happen, maintenance engineering must clearly state logistic support goals, objectives, and requirements in the request for proposal. These inputs exert considerable influence on selection of the system approach, and should be prepared in a manner that provides the potential validation contractors with a firm basis for proposing a plan for logistic support which addresses all of the support elements. The scope must be sufficiently comprehensive to insure that a given contractor's response, within the context of his proposed support plan, will describe all anticipated demands in such depth that unique or complex features are readily identifiable, and will include associated life cycle cost predictions.

In general, maintenance engineering should insure that those portions of the request for proposal dealing with support fully reflect the plans and conclusions that have resulted from the conceptual phase, and request their refinement or improvement by the contractor. Some typical specifics follow:

a. Maintenance Plan:

(1) Provide the maintenance concept, and request its expansion and refinement.

(2) Specify the minimum trade-offs to be conducted among operational, maintenance, and support parameters.

(3) Encourage contractor analysis to identify additional trade-off requirements.

(4) Request comprehensive justification for proposed maintenance parameters.

b. Support and Test Equipment:

(1) Identify support and test equipment items or philosophy resulting from conceptual studies.

(2) Define functional requirements for new equipment to a depth that will permit planning for its development.

(3) Request a plan that identifies and justifies each equipment item, and states how and when it will be acquired.

c. Supply Support:

(1) Request supply management and provisioning plans.

(2) Request identification of long lead time items.

(3) Request repair part cost estimates.

d. Transportation and Handling:

(1) Request identification of packaging, preservation, transportation, and handling requirements for initial delivery of materiel and for subsequent movement.

(2) Request a plan for satisfying all requirements, showing schedules, proposed packaging, and transportation modes.

(3) Request identification of any transportation and handling requirements that cannot be satisfied by standard Army or commercial vehicles, and identification of reusable container requirements.

e. Technical Data:

(1) Designate the specifications that will govern technical data preparation.

(2) Request a list of technical data required for materiel operation and support.

(3) Request a plan for development, production, and distribution of the data.

(4) Request a description of contractor experience and the personnel and facilities the contractor will use to prepare and produce technical data.

f. Facilities:

(1) Provide conceptual phase data.

(2) Request verification or modification of conceptual data.

(3) Request plans for establishment of facility design criteria and for interfacing with the Army Corps of Engineers and other Army agencies.

(4) Request a complete plan for facility acquisition.

g. Personnel and Training Requirements:

(1) Provide conceptual phase findings.

(2) Request identification of materiel items that generate requirements for new or additional training.

(3) Request estimates for qualitative and quantitative personnel requirements and identification of new skills.

(4) Request identification of training equipment requirements.

(5) Request human engineering studies.

(6) Request a plan for satisfying the requirements.

h. Logistic Support Resource Funds:

(1) Provide costing ground rules.

(2) Request desired cost estimates.

i. Logistic Support Management Information:

(1) Designate specifications that define the range and depth of the desired data system.

(2) Request a plan for acquiring the data system by direct application of a system in being, modification of an existing system, or new development.

(3) Request a description of how the data system will be used in the contractor organization for support management that assigns responsibilities to organizational elements for data development, storage, retrieval, and application.

Contractors respond to the request for proposal with proposals that explain how they will accomplish the work, and describe their qualifications. The first interval concludes with selection of the successful contractors—normally, two or three.

2-3.2 CONTRACTOR EFFORT

During the second interval, contractors perform the effort specified by the request for proposal, and additional innovative work they believe will add to the cost-effectiveness of the materiel. The products of their efforts are proposed plans for conducting a full-scale development program and supporting rationale, including analyses and trade-offs. Also included is a broad plan for contractor effort during the production phase.

Insofar as support is concerned, the trade-offs and analyses center on operational, maintenance, and support parameters, the maintenance concept, and cost. Such analysis will include any requirements for depot and factory maintenance, and need for extensive maintenance technical data. The depth of the work is limited by available information so th'at plans will include provisions for trade-off and analysis refinements during development, as well as for conducting additional analytical work. Quantitative operational, maintenance, and support parameters will be stated, and materiel life cycle costs will be estimated. All analytical effort is oriented toward demonstrating that the best possible balance has been achieved among total cost, design, support, schedules, and operational effectiveness.

A contractor version of a logistic support plan that addresses each support element is prepared by establishing element requirements and describing how they will be satisfied. Costs associated with contractor implementation **of** the plan are broken out as prescribed by the scope of work.

A plan for management of the support effort is included. The plan is comprised of organizational charts and narrative text. The charts show the relationship of the support developer to other contractor organizational elements. The narrative text describes the responsibility and authority of the support developer and other personnel in conducting the materiel program. Communication channels between the Government and the support developer, as well as between the latter and subcontractors and vendors, are delineated. Equally important, the plan describes all support management control data to be used, their sources, and the way in which the data are controlled and applied to the management process.

To provide essential background data for development planning, the contractor generates a broad plan for production and uses request for proposal data and assumptions to develop a deployment scenario. These also are included in the proposal.

2-3.3 EVALUATION OF CONTRACTOR REPORTS

Maintenance engineering evaluates the support aspects of contractor reports. The evaluation is conducted with the assistance of previously prepared evaluation criteria, but these must be augmented with historical data and experience. The general questions facing the evaluator concern cost-effectiveness, management capability, and program risk. To answer the general questions, the evaluator must examine the reports in minute detail and consider not only the merits of the plans for a particular support element, but also the impact of the plans on the remainder of the materiel program in both the design and support areas. Information obtained from such evaluations permits determination of both the validity of proposed efforts and the degree to which the planning should be reflected in an updated logistic support plan.

To insure that the proposed design and support and the support elements are in harmony and satisfy operational requirements, the following typical maintenance engineering considerations are required:

a. Maintenance Plan:

(1) Determine that the proposed plan is in consonance with the conceptual phase maintenance concept.

(2) Evaluate trade-offs, analyses, and parameters on which the plan is based.

(3) Assess the design, support, and cost impact of proposed diagnostic methods, packaging, and repair levels.

(4) Analyze preventive maintenance plans for adequacy and realism.

b. Support and Test Equipment:

. **(1)** Review operational and maintenance parameter trade-offs, and confirm the justification for each item of equipment, particularly special equipment.

(2) Determine the realism of plans for developing and acquiring special support and test equipment.

(3) Determine the adequacy of plans for providing maintenance and calibration services to deployed equipment.

c. Supply Support:

(1) Evaluate the overall supply management plan, including the provisioning plan.

(2) Consider the realism of cost estimates.

d. Transportation and Handling:

(1) Insure that preservation, packaging, transportation, and handling requirements are correctly identified.

(2) Evaluate contractor plans for initial delivery of materiel and repair parts.

(3) Carefully review any justifications offered for requirements to use special preservation and packaging techniques, special transportation and handling equipment, and reusable containers.

e. Technical Data:

(1) Assess the accuracy of the range and depth of technical data proposed for the materiel.

(2) Evaluate the worth of the overall technical data plan.

(3) Consider contractor experience and the adequacy of the resources he proposes to use.

f. Facilities:

(1) Analyze the contractor approach to developing facility requirements, and the accuracy of the results.

(2) Determine the adequacy of contractor plans for working with Government agencies in establishing design criteria and for supporting facility surveys and subsequent activities.

g. Personnel and Training:

(1) Evaluate initial proposed qualitative and quantitative personnel requirements for realism and completeness.

(2) Evaluate the authenticity of maintenance parameters used to project the support workload.

(3) Insure that proposed skill levels are compatible with the work to be accomplished.

(4) Consider the adequacy of the range and depth of proposed training courses and the types of training devices.

(5) Remember that personnel comprise the most scarce and expensive support resource.

h. Logistic Support Resource Funds:

(1) Evaluate for realism and responsiveness to the statement of work.

(2) Pay particular attention to the facts, assumptions, and techniques used in estimating life cycle costs.

i. Logistic Support Management Information:

(1) Evaluate the adequacy of the proposed range and depth of management information.

(2) Assess the plans for data generation, storage, retrieval, and application.

(3) Determine whether or not the contractor has delegated sufficient authority to support management to permit effective utilization of the data system.

(4) Consider the realism of proposed costs and schedules for the development of a new data system, or modification of an existing system.

After the proposals are evaluated, a contractor is selected, and each plan within the development plan is updated. The result is a complete documentation package that defines the materiel and desired support to a depth that permits negotiation of a definitive contract for their development. After this package is approved by higher authority, a development contract is negotiated with the previously selected contractor.

2-3.4 SUPPORT PLANS

The updating of the development plan is accomplished after a contract award has been made based on the proposals as originally submitted. In those cases where the Army has procured full rights to data in the proposals, which is normal, the best of these data are then synthesized, additional analyses and trade-offs are conducted as required, and the results are integrated into the plans that were prepared during the conceptual phase. Every plan in the development plan is affected. The discussion that follows is limited to significant changes in the plan for logistic support (Fig. 2-4), since this is the planning vehicle for maintenance engineering. The changes involve modifications of previous information, as well as the addition of considerable new information, as follows:

a. The schedule for logistic support planning is updated to reflect contractor schedules for accomplishing specific support events during full-scale development.

b. The basis for logistic support planning is modified to show an updated list of materiel, performance, and physical characteristics, and procurement status information.

c. The maintenance plan is extensively expanded. Maintenance parameter data are augmented, and definitive data pertaining to maintenance echelons and repair levels, packaging, diagnostics, depot support, maintenance floats, and maintenance test requirements are added.

d. The support and test equipment plan is updated to show a more complete list of equipment, the levels of maintenance to which it is allocated, and the plans for its acquisition.

e. The supply support plan is modified to show integrated Army and contractor plans for supply management and provisioning. Also, a preliminary list of long lead time repair parts is included.

f. The transportation and handling plan is updated by adding materiel transportability characteristics, special equipment requirements, preliminary total transportation requirements, and inkegrated Army and contractor responsibilities for satisfying the requirements.

g. The technical data plan is refined. Required technical data are specified in greater detail, and schedules for the development of technical data are included.

h. The facility plan is modified to include more information on technical criteria and a plan and schedule for the joint Army-contractor development of final technical criteria and subsequent facility acquisition.

i. The personnel and training plan is extensively modified. Qualitative and quantitative personnel requirements, planned training courses; training equipment requirements, and schedules are all modified and expanded.

j. The logistic support resource funds plan is modified to reflect contractor cost inputs.

k. The logistic support management information plan is expanded to include a description of the contractor data system to be used and an integrated plan for Army and contractor management of the development and acquisition of support.

The updated logistic support planning information provides the data required to modify several major plans within the development plan. Maintenance plan data are reflected in the system requirements and analysis and coordinated test program plans. The facilities plan contributes data to the facilities and resources plan. The personnel and training plan impacts the plan for personnel and training requirements. Finally, the logistic support resource funds plan provides additional information for the financial plan.

2-3.5 CONTRACTOR RECOMMENDED PLANS

The contractors selected to perform validation phase work on a major materiel program are required to prepare a contractor recommended support plan. This plan is similar to the logistic support plan (Fig. 2-4) in both composition and content. The major differences are that the contractor plan is more definitive and some of its component plan designations differ from logistic support plan designations. In spite of these differences, the subject matter covered by the two plans is virtually identical, as may be inferred from the designations of the following component plans, which comprise the contractor recommended support plan.

a. Management support plan

b. Support equipment plan

c. Repair parts and support plan

d. Personnel and training plan

e. Equipment publications plan

f. Facility plan

g. Contract maintenance plan

h. Technical assistance plan

i. Maintenance documentation and analysis plan

j. Maintenance evaluation plan

k. Transportation, packaging, and storage plan.

These plans, which are prepared during the validation phase, are really definitive work statements for contractor effort to be performed during full-scale development and general work statements for later phases. In each plan, the contractor defines requirements and states how he will further refine and satisfy them. In the management support plan, the contractor quotes a cost for the proposed services.

2-3.5.1 Management Support Plan

The management support plan describes the contractor's management structure and proposed management techniques for developing and acquiring support resources. The plan:

a. Describes the support management organization.

b. Provides for continual liaison with the Government to identify and solve problems affecting total support of the materiel under development.

c. Provides for subcontractor and vendor participation in the support program.

d. Provides for coordination of the support planning effort with associate contractors.

e. Provides for, on a selected basis, coordination with suppliers of Government-furnished equipment for optimum scheduling.

f. Provides a phased schedule of program milestones showing the time phasing of all significant tasks for support development.

g. Provides a reporting system for monitoring progress against all elements of the contractor recommended support plan.

h. Provides procedures for revising and updating the elements of the contractor recommended support plan throughout the development and production effort.

i. Provides a maintenance engineering analysis data system for tracing the impact of engineering changes on support elements.

j. Provides for application of modeling techniques to develop estimates of availability, maintenance frequency, maintenance burden, operational readiness float, repair cycle float, etc.

k. Lists the logistic data and information inputs required from the Government for items and equipment not under the control of the contractor.

l. Provides for effective execution and control of the trade-off process between design and logistic support aspects of the design.

m. Presents cost estimates to include:

(1) Cost of all support planning broken down by each component plan

(2) Cost of contractor implementation of the contractor recommended support plan

(3) Cost of operator and support personnel from initial issue to phaseout based upon criteria furnished by the Army

(4) Cost of repair parts and support from initial issue of materiel until phaseout

(5) Cost of all support equipment from initial issue of the materiel until phaseout

(6) Contractor funding requirements for support from development contract award until contract closeout

(7) All assumptions, criteria, and techniques used as a basis for estimates

(8) Total life cycle support cost broken down by fiscal year.

n. Presents recommendations for additional documentation, planning, or implementing 'actions deemed necessary for development and production not otherwise specified by the Army.

2-3.5.2 Support Equipment Plan

The support equipment plan describes the total program to develop and satisfy total support equipment requirements. The plan:

a. Describes how maintenance engineering analysis data will be used to develop support equipment requirements.

b. Identifies and describes overall requirements for support equipment covering the following categories:

(1) Equipment defined by Government specifications

(2) Commercial support equipment currently in the Federal Supply System

(3) Other commercially available or modified commercial support equipment.

(4) Specialized support equipment (modified or new) that is recommended for development.

c. Recommends provisioning procedures for support equipment.

d. Identifies requirements for long lead time items, and in the time-phased schedule, designates those tasks required for timely development and/or delivery of those items.

e. Identifies any items of Government-furnished materiel that are to be incorporated into the proposed support equipment.

f. Furnishes allocated configuration identifications for support equipment.

g. Substantiates and documents the results of cost-effectiveness studies and trade-off analyses conducted relative to support equipment.

2-3.5.3 Repair Parts and Support Plan

The repair parts and support plan provides procedures and schedules for identifying, provisioning, and delivering repair parts and maintenance floats. The plan:

a. Recommends provisioning procedures to cover repair part requirements for operating and support materiel for all categories of maintenance during subsequent life cycle phases.

b. Identifies the need for provisioning special supplies for support of the materiel under development.

c. Describes an approach for utilizing a data system to document repair parts and support requirements.

d. Substantiates and documents the results of cost-effectiveness studies and trade-off analyses conducted relative to repair parts and support requirements.

2-3.5.4 Personnel and Training Plan

The personnel and training plan identifies operator and support personnel requirements and training requirements, and presents a plan and schedule for satisfying the requirements. The plan:

a. Identifies all items of equipment that will require new or additional training of Army operator or support personnel.

b. Provides for human engineering studies to develop requirement and constraint input data for design engineering.

c. Provides for definition and resolution of interface problems between hardware and personnel.

d. Provides for development of quantitative operator and support personnel requirements.

e. Provides for development of operator and support personnel skill (qualitative) requirements.

f. Provides for identification of quantitative and qualitative personnel deficiencies based upon known or planned force structure and manning data and information.

g. Provides for determination of new and additional training requirements and identifies the sources of training (established Government courses, contractor training programs, etc.).

h. Provides for development of contractor conducted training courses.

i. Provides for development of training equipment requirements.

j. Provides for preparation of training equipment specifications for Government approval.

k. Develops input data for the technical assistance plan.

l. Substantiates and documents the results of cost-effectiveness studies and trade-off analyses conducted relative to personnel and training requirements.

2-3.5.5 Equipment Publication Plan

The equipment publication plan provides procedures and schedules for identification, preparation, and delivery of all publications required for materiel operation and support. The plan:

a. Describes and lists all Department of the Army equipment publications (including maintenance allocation charts) needed to support the materiel for all categories of maintenance during development, production, and operational use.

b. Describes and lists all commercial literature in lieu of Department of the Army publications needed to support the materiel for all categories of maintenance during development, production, and operational use.

c. Describes and lists all instruction books needed to support the materiel for all categories of maintenance during development, production, and operational use.

d. Describes the verification program to be used for certifying the achievement of overall equipment publication program requirements.

e. Describes the means and methods of utilizing a data system in the development of the equipment publication requirements.

f. Substantiates and documents the results of cost-effectiveness studies and tradeoff analyses conducted relative to equipment publication requirements.

g. Provides for the preparation and use of printouts of change order reports to insure that appropriate changes are made in specific publications.

h. Provides for analysis to determine anticipated publication problems and any foreseeable departures from established publication practices.

i. Provides 'for Government quality control reviews to insure that the technical content, format, and composition of equipment publications meet an acceptable level of quality based upon established standards.

2-3.5.6 Facility Plan

The facility plan presents requirements and schedules pertaining to materiel operational and support facilities. The plan:

a. Provides for the determination of Government facility requirements for operation, maintenance, supply, and training.

b. Establishes facility design criteria. Actual facility surveys will be sponsored by the Army unless otherwise specified.

c. Describes the application of a data system for determining facility requirements.

d. Presents lead time requirements and schedules for the activation of facilities.

e. Substantiates and documents the results of cost-effectiveness studies and trade-off analyses conducted relative to facility requirements.

2-3.5.7 Contract Maintenance Plan

The contract maintenance plan defines the requirement for and schedules the accomplishment of contract maintenance. The plan:

a. Defines the requirements for contract maintenance support of materiel being developed.

b. Develops procedures for initiation and termination of contract maintenance.

c. Provides for determination of resources (facilities, tooling, support equipment, repair parts, Government-furnished equipment, personnel, etc.) required for contract maintenance.

d. Provides for documentation of contract maintenance procedures, requirements, and data.

e. Substantiates and documents the results of cost-effectiveness studies and trade-off analyses conducted relative to contract maintenance requirements.

2-3.5.8 Technical Assistance Plan

The technical assistance plan defines the requirements for and schedules the accomplishment of contract engineering and technical services. The plan:

a. Makes recommendations and identifies materiel that will require field service representatives for support.

b. Indicates the number of field service representative personnel, by skill, that will be needed for assignment on a unit or area basis.

c. Provides a delineation of field service representative duties, including but not limited to on-the-job training and technical guidance to military and civilian personnel in assembly, installation, testing, adjusting, operation, and maintenance of materiel to be supported.

d. Provides information on establishment of skill levels for field service representatives, including education levels, experience on the materiel to be supported, experience on similar or related materiel, and any other qualifications required to perform efficiently the necessary field services.

e. Provides a schedule of the training program for field service representative personnel.

f. If applicable, provides a schedule of field service representative assignments for Military Assistance Program contractor support services.

g. Specifies the facilities, services, and materiel needed to implement properly the plan for technical assistance.

h. Provides procedures for phaseout of field service representatives.

i. Substantiates and documents the results of cost-effectiveness studies and trade-off analyses conducted relative to technical assistance requirements.

2-3.5.9 Maintenance Documentation and Analysis Plan

The maintenance documentation and analysis plan describes a technical data management and control system for the derivation and application of technical data, including maintenance engineering analysis data, to the development and acquisition of support resources. The contractor may propose application of an existing data system, modification of an existing data system, or development of a new system. In any event, the plan:

a. Describes a data system capable of recording and transmitting source data to satisfy the following basic support planning requirements:

(1) Annual and life cycle support costs

(2) Maintenance support costs by categories of maintenance

(3) Comparison data (anticipated as historical information; e.g., The Army Maintenance Management System)

(4) Alternative maintenance doctrine

(5) Task, skill, and manpower analysis at operating levels and maintenance categories

(6) Maintenance man-hour/task data (including maintenance calibration and calibration requirements)

(7) Analysis and evaluation data relevant to support concepts and requirements

(8) Engineering drawings and specification data, generation breakdown of end items, parts lists, engineering data, and cross-reference lists

(9) Weight, transportability, and packaging data

(10) Recommended provisioning list and provisioning documentation as required by the statement of provisioning requirements

(11) Recommended allocation of maintenance tasks and operations

(12) Equipment publications documentation (including technical procedures and standards, repair parts, tools, and test equipment identification, and allowance data)

(13) Maintenance float requirements

(14) Depot maintenance technical manuals

(15) Draft equipment publications

(16) Initial prescribed load list

(17) Initial authorized stockage (basic load) list.

b. Establishes procedures for correlation and distribution of the data acquired in other support elements that are prerequisite to the development of any given support element. For example, the preparation of equipment publications involves data pertaining to description, theory, operation, packaging and packing, transportation and handling, storage, maintenance tasks and requirements, maintenance allocation chart, tools and test equipment, repair parts, lubrication, maintenance calibration, and calibration.

c. Presents a maintenance engineering analysis of data and design information from development and product assurance sources. The analysis identifies measurable support requirements, including reliability and maintainability requirements. The analysis is documented in the data system and becomes the basis upon which the various component support element plans are formulated.

d. Provides for accomplishment of cost-effectiveness studies and trade-off analyses ,relative to each support element.

e. Provides for the reporting of failure and trade-off data.

2-3.5.10 Maintenance Evaluation Plan

The maintenance evaluation plan describes contractor support for maintenance evaluation by the Army of developed materiel. The plan:

a. Provides recommendations for contractor-furnished support items and data required by Government personnel to accomplish maintenance evaluation during reviews, physical teardown, test, and demonstration.

b. Includes schedules for informal and formal design reviews, to be held periodically, during which all maintenance features of the materiel are considered as an integral part of the contractor's engineering design review procedures.

c. Includes schedules and plans for a demonstration and test program. The tests are designed to provide estimates of maintainability achievement and to define problem areas for corrective action.

d. Describes the extent to which subcontractors or vendors will support demonstration and testing of materiel.

e. Presents procedures for a formalized system for collecting, recording, and analyzing all failures, and performing trade-offs during contractor installation, checkout, testing, and evaluation, starting at the engineering test stage.

2-3.5.11 Transportation, Packaging, and Storage Plan

The transportation, packaging, and storage plan describes the contractor's proposed effort to develop procedures and requirements for protection and transportation,of equipment to the point of initial delivery and during subsequent movement. The plan:

a. Establishes requirements and procedures that will provide protection for all parts, components, subassemblies, and final assemblies during transportation from suppliers, storage, transit, manufacturing processes, final shipment to the customer, and subsequently. When the requirements cannot be satisfied in the design of the items, packaging and packing methods shall be used to reduce transportation and handling hazards to a minimum. The primary objective will be to insure, at a minimum cost, adequate protection against degradation in the reliability or functional capability of Government materiel.

b. Provides for transportation management that will develop transportation plans, coordinate and arrange the reliable, expeditious, and economical movement of materiel, and select methods and types of transportation consistent with geographical considerations, responsibilities, and environmental and schedule requirements.

c. Determines the requirements for Government-furnished information, materiel, and equipment, and schedules the requirements during the development and production phases.

d. Substantiates and documents the results of cost-effectiveness studies and trade-off analyses conducted relative to transportation, packaging, and storage requirements.

2-4 FULL-SCALE DEVELOPMENT

Two objectives of the full-scale development phase involve demonstration and documentation. Analyses and tests are conducted to demonstrate that materiel and the planned support subsystem will be cost-effective in the operational environment in which the materiel is to be deployed. Documentation is prepared for use in acquiring the total materiel system. For operating and support materiel, this documentation consists of specifications, drawings, and other production related material. For non-materiel support resources such as personnel, the documentation consists of detailed requirements and final acquisition plans.

During the full-scale development phase, maintenance engineering reaches its maximum activity in influencing design and defining support. These functions are accomplished concurrently, and they are interdependent. The depth of design information available at the start of the development phase is not great, yet the phase ends with production-type hardware and its support subsystem. The need for expeditious and diligent application of all maintenance engineering tools and techniques toward insuring an optimum design and support subsystem is apparent.

Numerous design versus support trade-offs are conducted by maintenance engineering as design evolves. Optimum benefits are realized when design deficiencies are identified and design changes can be incorporated before development materiel is fabricated. In general, the trade-offs involve maintenance parameters versus support parameters; and maintenance parameters, coupled with support parameters, versus operational parameters. Design changes resulting from maintenance engineering requirements, or from other causes, are analyzed for support requirement impact; and these requirements are updated. Off-the-shelf ground support equipment is evaluated for maintainability and suitability in the early development stage. This will include an assessment of training requirements for Government-furnished equipment and contractor-furnished equipment.

Drawings become available early in the development phase. At this point, a formal maintenance engineering analysis documentation system is initiated. This is a powerful tool for use in identification and control of further design and support changes. Each change triggers a new evaluation cycle to define impacts and trade-off choices between design and support. Results are fed back to the separate functional support elements for evaluation and impact. Design and support changes require updating of technical data on a continuing basis. Preliminary data should be prepared in a format that can be expanded later and formalized for use in the production and operational phases of the life cycle.

A major source of design information and a means of impacting design are afforded by informal and formal design reviews. The informal reviews are conducted on an opportunity basis, and involve inspection of mock-ups, breadboard models, etc. Such models are available relatively early during development, and are particularly valuable because the three-dimensional presentations permit a more accurate evaluation of human factors, safety, and some maintenance parameters than are permitted by drawings. Such reviews, conducted in concert with design engineering, can result in desirable on-the-spot design changes.

Formal design reviews provide another excellent opportunity for effecting design changes. The reviews are scheduled periodically for the purpose of reviewing the status and progress of the total development effort for both materiel and support. Attendees submit formal comments to program management. Maintenance engineering evaluates and comments on support related subjects such as:

a. Conformance to specified maintainability criteria

b. Adequacy of descriptions of maintenance procedures

c. Conformance of maintenance procedures to human factor standards

d. Conformance to safety standards

e. Compatibility of the maintenance concept with planned support resources and the current design configuration

f. Adequacy of the maintenance plan

g. Acceptability of parts and material selection and application

h. Realistic maintenance float and repair part provisioning requirements

i. Adequacy of planned maintenance facilities

j. Adequacy of maintainability verification/demonstration/evaluation plan.

A final means of evaluating the adequacy of materiel design versus planned support is offered by demonstrations and tests conducted during the development phase. A physical teardown evaluation is conducted to verify materiel maintainability, adequacy of planned support resources, and assignment of maintenance tasks to appropriate maintenance levels. Also, full-scale development demonstrations and operational tests are conducted in a simulated operational environment. The demonstrations and tests afford an ideal vehicle by which to assess the worth of the support subsystem, and an opportunity to take a last look at design before production is initiated. Although the incorporation of design changes at this time is expensive, production changes cost even more and pose a greater management problem.

During the latter part of the development phase—typically, at least 120 days prior to the initiation of the production contract—the Army convenes a provisioning conference. The range and quantity of support equipment and repair parts to support the initial buy of prime equipment for a specified period of time are determined, and the contractor is directed to take those actions necessary to produce and deliver the support items with the prime equipment. Alternatively, phased provisioning might be' used. This is a management refinement to the provisioning process whereby quantity procurement of selected items is phased by time interval into the later stages of production, thereby enhancing the ability of the provisioning activity to make more cost-effective decisions.

2-4.1 SUPPORT PLANS—WORK STATEMENTS

The support plans developed in the validation phase are revised in accordance with work statements negotiated for the full-scale development contract. The Army and contractor implement and revise these plans throughout the development and subsequent phases. At this time, the plans are qualitatively complete, but most quantitative values and details relative to ways and means of accomplishment are subject to refinement as a result of development phase activities.

2-4.1.1 Management Support Plan

The Armyhontractor will implement the revised plan and:

a. Designate a specific support manager and an alternate who will be responsible for all phases of the support program.

b. Refine the schedule of the management support plan.

c. Periodically update the support development cost analysis information in accordance with the contract schedule but not less often than semiannually.

2-4.1.2 Support Equipment Plan

The Army/contractor will implement the revised plan and:

a. Identify, evaluate, and record all support equipment required for receipt inspection, calibration, maintenance, storage, processing, and shipment of materiel for all categories of maintenance.

b. Update and provide additional allocated configuration identifications.

c. Accomplish changes to support equipment requirements data due to revision of materiel design.

d. Use a data system to define and provide calibration support requirements. Develop calibration requirements in the following three phases, to be performed in the order shown, and only after Government approval of the results of each phase:

(1) Phase I. Engineering research to determine parameters, methods, frequency, and level (primary, reference, transfer, or maintenance calibration) of requirement as reflected in an engineering report.

(2) Phase 11. Preparation of detailed procedural, inspection, maintenance, and test data required to support each calibration technique.

(3) Phase 111. Preparation of appropriate procedural technical bulletin manuscripts in accordance with the equipment publication plan.

e. Upon completion of Phase 11, conduct a dynamic evaluation of the validity of calibration procedures and standards. The results shall be verified and approved by the Government.

f. Provide list(s) as specified by the Government, showing the adapters, special equipment and devices, commercial equipment, measurement standards, gages, and accessories required to accomplish calibration.

g. Promote standardization of support equipment by researching published equipment data, or by providing to mission responsible managers the data required to research their records for the availability of a suitable item. The Government will provide the contractor with lists of inventory control points responsible for support equipment items (tools, test, measuring, and diagnostic), including support equipment that is type classified as standard. The contractor will consider the following order of priority in preparing recommendations and justification:

(1) Support equipment currently available at the activity responsible for maintaining the equipment in question

(2) Support equipment that is type classified as standard by the U.S. Army, but is not currently authorized to the particular maintenance organizations concerned. Selection of these items shall be made from documents available from the U.S. Army.

(3) Support equipment that is type classified as standard by the U.S. Air Force or the U.S. Navy

(4) Off-the-shelf commercial support equipmen.

(5) Support equipment that must be developed by the contractor or some other manufacturer.

h Determine requirements for technical data for the development of specialized support equipment or procurement of commercial off-the-shelf items to permit their acquisition through competitive bidding when such equipment is not available as a result of activity otherwise accomplished in this plan. Upon approval by the Government, the contractor shall develop such data on selected items.

i. Identify and schedule development and delivery of the prototype support equipment to be supplied concurrently with materiel under development for maintenance evaluation during physical teardown, engineering test, service test, and initial production test.

2-4.1.3 Repair Part and Support Plan

The Army/contractor will implement the revised plan and:

a. If the contract scope of work calls for the contractor to supply all repair parts for a specified period of time, provide a plan for transition from contractor to Government support. Otherwise, consider all support available through the military supply system.

b. Use maintenance engineering analysis data, and provide current lists of all repair parts by category of maintenance.

c. Use maintenance engineering analysis data and provide current lists of special supplies (lubricants, cleaners, solvents, fuels, etc.) required for support of materiel at each category of maintenance.

d. Plan for repair part acquisition, availability, and storage during test and evaluation. Minimum quantities of repair parts will be furnished. High cost parts will be selected only after consideration of downtime cost, repair cost, and program impact. Arrange with vendors and subcontractors for the supply of repair parts, and with the Government when Government-furnished equipment support is involved.

e. Provide repair part usage data accumulated during test and evaluation and other periods.

f. Make, as a part of all purchase inquiries, the requirement that each supplier disclose in his bid any proprietary or limited rights involved. Promptly notify the Government upon receipt of the knowledge that a limited rights item will be used.

2-4.1.4 Personnel and Training Plan

The Armyhontractor will implement the revised plan and:

a. Develop data necessary for the preparation and submission of a task and skill analysis and a new-equipment training requirement report, and prepare a complete report.

b. Provide for preparation and submission of a new-equipment training plan that covers training requirements for all categories of maintenance.

c. Provide for preparation, submission for approval, reproduction, and distribution of programs of instructions for each course specified in the approved new-equipment training plan.

d. Provide for preparation, submission for approval, reproduction, and distribution of lesson plans, practical exercise guides, lesson manuscripts, and film guide sheets.

e. Provide for training devices as specified in the approved training plan. Training devices will be designed, developed, and procured in accordance with separate documentation.

f. Provide for training aids (other than training devices) specified in the approved training plan.

g. Provide a list of hardware and a list of special equipment required for contractor conducted training.

h. For new equipment training, provide:

(1) Training personnel for planning, preparing, and presenting the required instruction

(2) Facilities and equipment for training, administration, and maintenance support

(3) Administrative services required in the maintenance of class records and related forms and records.

i. Complete and submit certificate of service and accomplishment report.

2-4.1.5 Equipment Publication Plan

The Armyhontractor will implement the revised plan and:

a. Provide for preparation of equipment publications in accordance with appropriate regulations and equipment publication military specifications.

b. Use all accumulated data and files pertinent to the development of equipment publications.

c. Provide for preparation and availability of preliminary draft equipment publications for engineering design test and prototype system review.

d. Provide for preparation and availability of draft equipment publications, or approved substitutes, for evaluation during engineering tests, service tests, and initial production tests. The draft equipment publications will include calibration procedures, as applicable, and a draft maintenance allocation chart.

e. Provide for verification of draft equipment publications. Verification of data shall not duplicate that required for other support elements.

f. Provide for Government quality control reviews to insure that the technical content, format, and composition of draft publications meet an acceptable level of quality based upon established standards.

g. Provide for preparation of change order reports (publications) to provide details pertaining to specific publications affected by engineering change orders and field reports.

h. Provide for monthly preparation of a technical publication progress/cost report to reflect the current status of the publication effort.

i. Provide for preparation and availability of a preliminary maintenance allocation chart prior to physical teardown and evaluation.

2-4.1.6 Facility Plan

The Army/contractor will implement the revised plan and:

a. Monitor program changes and recommend changes in facility requirements at all support levels.

b. Provide for evaluation of specific Government facilities and submit recommendations for their use and/or modification when specifically requested by the Government. The contractor will not be responsible for conducting site surveys and examining existing Government-owned facilities. The Government will appraise existing Government facilities with respect to the contractor furnished design criteria in order to effect efficient use of such facilities. In the event that existing facilities are not adequate, the Government will take action to construct new facilities or to modify existing facilities.

2-4.1.7 Contract Maintenance Plan

The Army/contractor will implement the revised plan and:

a. Schedule performance of the specified maintenance.

b. Identify and list. the resources required for contract maintenance.

2-4.1.8 Technical Assistance Plan

The Armyhontractor will implement the revised plan and:

a. Identify and list the materiel that will require field service representatives for support.

b. Refine field service representative qualitative and quantitative personnel requirements.

2-4.1.9 Maintenance Documentation and Analysis Plan

The Army/contractor will implement the revised plan and:

a. Initially include in the data system the preliminary forecast information generated for formulating the validation phase plans and proposals. **As** the materiel develops, replace this information with more precise experience data in order to provide a comprehensive basis for maintenance support planning decisions. Maintain the data system in a current status in order to insure availability of reliable information in developing effective and economical support procedures.

b. Develop, in detail, the selected support alternatives derived from validation phase proposals. Quantitative values for maintainability, reliability, and support efficiency, as well as the maintenance parameters that follow, will be determined for each of the alternative methods of support. The parameters will include but not be limited to the following:

(1) Scheduled preventive maintenance downtime

(2) Supply downtime

(3)' Corrective maintenance downtime

(4) Downtime for all other causes

(5) Direct maintenance man-hour requirements

(6) Cost of support equipment

(7) Repair cost

(8) MOS's and skill levels of maintenance personnel

(9) Identification of support materiel required.

c. Initiate cost-effectiveness studies, based on definitive cost data, for each of the support alternatives. The results of these studies will reflect weighted consideration of each of the support parameters.

d. Submit results of the support alternatives and cost-effectiveness studies, together with recommendations and justifications for final development of a specific support approach.

e. Upon approval of a specific support approach, initiate any action that may be required to clearly define the qualitative and quantitative requirements associated with the elements of support.

f. In making maintenance engineering analyses, use the information made available through the data system to arrive at decisions affecting materiel design and materiel support. Perform reliability analysis, maintainability analysis, studies of logistic and design alternatives, and a thorough and complete analysis of the support element requirements. Maintenance characteristics of the equipment and components will be determined in terms of their contribution to the overall maintenance characteristics of the system operational requirements at each category of maintenance. The factors to be considered shall include but not be limited to mean time between failures, mean time to repair, mean time for scheduled maintenance, operational requirements, skills, special equipment, maintenance facilities, and mean downtime. Functional area analysis will be accomplished through the individual project offices; i.e., the offices responsible for materiel design, support planning for personnel and training, and equipment publications.

g. Conduct an analysis of reliability and maintainability data and documentation. The analysis will be conducted as part of the maintenance engineering analysis. This analysis will be conducted as part of the overall reliability and maintainability program planning in order to review and assess the application of those reliability and maintainability principles that affect support. The analysis shall contain a review and evaluation of design parameters, maintenance characteristics, equipment compatibility factors, and design trade-offs to identify changes to the support profile which affect the maintenance burden. As a result of the reliability and maintainability analysis, as well as actual experience data, maintenance allowance factors will be derived. These factors will be used to convert "pure time" estimates appearing in maintenance engineering analysis data sheets to total maintenance time.

2-4.1.10 Maintenance Evaluation Plan

The Armyhontractor will implement the revised plan and:

a. Provide maintenance documentation and data support for maintenance evaluation.

b. Provide resources to support the maintenance evaluation such as personnel, facilities, prototype models, support equipment, technical documentation, preliminary draft equipment publications, and repair parts.

c. Provide a maintenance task and skill analysis and human and safety engineering data for evaluation and verification.

d. Recommend appropriate contract changes if any changes to materiel resulting from the maintenance evaluation are not covered by the scope of the existing contract.

e. Recommend disposition of test specimens and materiel associated with the maintenance evaluation.

2-4.1.11 Transportation, Packaging, and Storage Plan

The Army/contractor will implement the revised plan and:

a. Determine and furnish for coordination with the procuring activity the characteristics of each special design package item. Examples of characteristics to be listed are:

(1) Size, weight, and shape

(2) Material of construction and surface finishes

(3) Susceptibility to damage, or deterioration from shock, vibration, corrosion, or contamination

(4) Practicable disassembly

(5) Value of equipment in terms of its costs and importance to the program

(6) First destination and anticipated subsequent movement or relocation

(7) Transportation models and associated environments

(8) Duration of storage and associated environments

(9) Economics and practicality of reusing container

(10) Provisions for storage and easy accessibility of necessary forms and/or records.

b. Provide for the preparation of detailed design drawings or specifications to be used as production procurement data for each special design container.

2-4.2 TRADE-OFFS AFFECTING MAINTENANCE

During development, maintenance engineering analysis data are used to maintain compatibility between design and the total support package, as well as between the support elements. The data also initiate trade-offs and serve as trade-off inputs.

The data generated by the maintenance engineering analysis process define the maintenance actions that must be performed and the support resources required to support the actions. To insure that these data are not merely accumulated and then ignored, a standardized data system for recording, processing, storing, and reporting analysis results is used. Proper utilization of this system insures that support requirements pertaining to resources such as support equipment, repair parts, and personnel are compatible with current materiel design and with planned activities such as provisioning and training. Compatibility is virtually assured, because all information flows from a common integrated data base.

A second and equally important contribution of the data system is that it sometimes identifies support trade-off requirements and always provides support trade-off inputs. The identification of trade-off requirements occurs when maintenance engineering analysis data highlight a potential problem such as a prohibitive requirement for some resource, or the fact that required maintenance activities at some level violate established maintenance policies. With regard to trade-off inputs, it is not possible to conduct a support trade-off without identifying in some quantitative manner (usually dollars) the support resources dictated by each alternative.

Prior to and during the initial part of the development phase, trade-offs and resulting design and support decisions are based first on conceptual and then on predicted data. As design progresses and hardware is fabricated and tested, maintenance engineering analysis data make ‘a transition from a predicted to an observed status. This is a critical period for maintenance engineering. If any of the predicted data are significantly wrong, the requirements and plans for some or all of the support elements will be in error. Immediate trade-offs are required to determine whether it is more cost-effective to stay with the design and modify the support plans, modify the design to satisfy the previously predicted data, or to modify both the design and the support plans. The data that have been systematically compiled to this point are of great assistance in identifying trade-off alternatives, and provide many of the required trade-off inputs.

Thus a primary purpose of the trade-off technique is identifying, reducing, and controlling the need for extensive logistic support resources.

2-5 PRODUCTION

The production phase overlaps both the full-scale development and the deployment phases (Fig. 2-1). It is initiated with an updating of all support plans, and ends when all materiel and support resources are deployed. Actually, a limited production capability to modify materiel normally is maintained throughout the life cycle, but this capability is not a production function in the sense of this discussion.

At the start of the production phase, support plans are updated to reflect any changes brought about by development phase activities. Subsequently, the plans are implemented and revised as necessary. One of the first activities required by the updated plans is the conduct of development and production tests with early production materiel. The objectives of the development tests are to verify that the materiel meets specifications and that previously discovered deficiencies have been corrected. The objectives of the operational tests are to refine or validate earlier estimates of operational effectiveness, determine the operational suitability of production materiel, optimize organization and doctrine, validate training and support requirements, and identify any additional actions to be taken before materiel deployment. Test difficulties result in revised materiel and support plans and in delayed production. Otherwise, implementation of the previously updated plans continues. This essentially involves the delivery of hardware and software.

The support equipment and repair parts provisioned during full-scale development (par. **2-4)** are produced and delivered. If phased provisioning was used, one or more provisioning conferences will be convened after usage experience is available, and additional support items will be manufactured and delivered. Training equipment, aids, and devices are delivered, and new-equipment training courses are conducted. Army training schools are activated, and materiel operator and maintenance courses are conducted. Organizational, field, depot, and supply equipment publications are prepared and printed. Operating and support materiel is delivered, along with appropriate logs and records, and technical assistance is provided when specified in the approved plans.

The production phase is characterized by considerable maintenance documentation and analysis activity. Existing prediction data are updated and refined with actual usage data as they become available. Generally, the data procedures do not change during this phase; however, reporting requirements may be revised to provide new or additional feedback information pertaining to equipment corrective actions and operation and maintenance information. This information is routed through the established data documentation and analysis system. Proposed plans are prepared for the eventual transfer of the data bank to the Government for use in comparing anticipated results with actual results. During this phase, the contractor coordinates between the functional areas of materiel design, support planning, and manufacturing through the documentation and analysis system. Maintenance engineering analysis data form the basis for final preparation of the contractor recommended support plan. Planning efforts are directed by the contractor's support manager in order to plan and schedule an orderly transition of all functions of materiel support management from the contractor to the Government. The Government will achieve this capability through gradual integration and implementation of the contractor recommended support plan.

In addition to the foregoing, maintenance engineering performs its normal function of maintaining compatibility between design and support. Proposed design changes are evaluated for their support impact before approval. If approved, support plans and support resources are appropriately modified, and modified resources are delivered concurrently with installation of the modification.

2-6 DEPLOYMENT

The deployment phase of the life cycle starts when the first military unit is equipped and ends when the materiel has been declared obsolete and is removed from the Army inventory. The deployment period is characterized by supply, training, maintenance, overhaul, and materiel readiness operations conducted by operational and support units and depots. This period is significant because it is here that the quality and completeness of previously accomplished maintenance engineering are demonstrated. Performance is measured in terms of both effectiveness and economy of operations and support.

Maintenance engineering monitors the performance of the support subsystem during this period by acquiring and analyzing field data and equipment improvement recommendations. Modification requirements may result from these activities. The impact of design changes is reflected in revised support plans and support resource quantities.

Changes in the basis of issue, new unit activations, or any submissions of demand data indicating reprovisioning or replenishment requirements necessitate supply support studies for revisions of requirements and subsequent procurement activities. Rebuild or modification programs that become active also necessitate supply support activities.

Changes or revisions to equipment publications are developed to reflect new or different component parts in materiel and to cover changes in the selection of repair parts or in the allocation of maintenance functions. Many of the changes and revisions are the result of materiel modifications. Such changes are required concurrently with the publication of modification work orders.

Based on the depot maintenance support plan, requirements are developed, programmed, and scheduled to mission depots, to contractors, or to both. Repair part support requirements for the program are refined, and balanced workloads are established for depots. Production schedules and costs are reviewed, and determinations are made to insure that costs are reasonable, production is adequate, and schedules are attained.

2-6.1 DATA ANALYSIS

Maintenance engineering conducts systematic data analyses throughout the deployment phase to evaluate support effectiveness. One analysis method is the use of a sample data collection program that is based on statistical sampling techniques. Sample data are obtained from specific units in designated geographical areas for a limited period of time. These data are representative of the total deployed force, and may be used in support effectiveness analyses and in forecasting future support requirements (Ref. 3).

A typical use of data analysis is to refine forecast depot overhaul requirements. The time between overhauls for materiel is established initially by using development and operational test data. As usage data from operating units become available, failure trends are identified. These trends may result in a revision of reliability predictions, which in turn necessitates revisions to the time between overhauls and float item requirements. As the time between overhauls is changed, depot maintenance support must be increased or decreased accordingly in order that sufficient end items and component assemblies can be maintained at the depot and in the supply pipelines. This action continues throughout the operational life of the equipment.

Maintenance engineering obtains data for the sampling program, as well as for other purposes, from The Army Maintenance Management System. This system establishes requirements for organizations to maintain the following records for the reasons indicated (Ref. 3).

a. Operational Records. These records provide the means of control of operators and equipment, operational planning, and optimum use of equipment.

b. Maintenance Records. These records are established to control maintenance scheduling, inspection procedures, and repair workloads. They provide a uniform method for recording corrective action taken by responsible maintenance elements. These records are used in determining the current status of equipment readiness, reliability of equipment, utilization, and logistical requirements. Certain records are designed to permit analysis of causes of equipment failures and mortality rates of components.

c. Equipment Historical Records. Equipment logs are the historical records for individual items of Army equipment. They are the permanent record of information pertaining to the receipt, operation, maintenance, modification, transfer, and disposal of equipment.

d. Ammunition Records. Ammunition records and procedures are prescribed to improve control and status reporting of munitions.

e. Calibration Records. Calibration records and procedures are prescribed for the control of this function for Army equipment.

2-6.2 MATERIEL MODIFICATIONS

The equipment improvement recommendation is the document by which users of Army equipment report equipment faults in design and manufacture or propose improvements in materiel. It is used to initiate the action required to correct equipment failures, deficiencies, and shortcomings; to improve the performance of equipment; and to insure that use-experience is incorporated into research, design, development, and production efforts relative to new equipment of a similar type. All recommendations are investigated and evaluated by maintenance engineering. Determinations are made regarding requirements for changes to produced materiel, materiel in the production process, and to future procurements, as well as to the adequacy of publications and training. The support impact of possible modifications is determined. Coordination with design elements is mandatory so that reliability and maintainability parameters can be reevaluated (Ref. 4).

Modification of equipment is authorized to assure the safety of personnel, prevent serious damage to equipment, increase to a significant degree the combat effectiveness of equipment, simplify or reduce required maintenance, make equipment in use compatible with new equipment, and eliminate compromises relative to communication security. Deciding whether or not equipment should be modified entails a consideration of the following conditions and functional aspects (Ref. 5):

a. The age of the item

b. The remaining life expectancy of the item, including a consideration of procurement lead time as it applies to the modification kit. The term "life expectancy" as used in this discussion refers to the time remaining before an item is scheduled to be phased out of the system, is scheduled to be replaced by a new item, or is anticipated to become unserviceable because of fair wear and tear.

c. The type classification of the item

d. Cost-effectiveness as it applies to the seriousness of the deficiency and to a comparison of benefits derived from the modification as compared with the cost of the modification

e. Both the density and the mission essentiality of the materiel.

If investigation reveals that no action is required with regard to the equipment improvement recommendation, its originator is so advised. If it is determined that a modification is required, an engineering change proposal is prepared that describes the full impact of the proposed change. After approval of this document, a modification work order is prepared.

The modification work order is an official publication that provides authentic and uniform instructions for altering and modifying Army materiel. It is a directive, and its application is mandatory. Work orders normally are classified either URGENT or NORMAL. The first classification is assigned when safety of personnel or equipment is involved. All other work orders receive the second classification. The modification work orders are sent to the proper field level with modification kits, and the work is accomplished. Materiel in the production process is modified online. Technical publications are revised, as required, and applicable repair parts are modified if possible, or are replenished by procurement. All activities are accomplished on a coordinated schedule that insures that proper support resources are available when using organizations become responsible for maintaining and operating the modified materiel.

Summaries of actions taken to resolve problems reported on equipment improvement recommendations are published in the equipment improvement report and maintenance digest technical bulletin. This bulletin is published quarterly to disseminate technical information concerning maintenance activities to field units and higher commands. It contains information on active and closed improvement reports, equipment publication changes, and current and delinquent modification work orders. The maintenance digest provides information reflecting the trend of support maintenance problems experienced by using units, and lists actions taken to resolve them. It has a one-time distribution and is not stocked as an item of supply in publication or supply points.

The *PS Magazine,* published by the Army Materiel Command, is not directly associated with modifications, but its contents sometimes forecast modification requirements and deal with support problems and solutions on an informal basis. The magazine information is drawn from the best available technical sources, and is furnished for operator and organizational maintenance use. The information comprises recommendations only, until such time as it is published as a formal directive or is authorized by appropriate authority. Information pertaining to any type of materiel in the Army inventory may be contained in the magazine.

2-6.3 DEPOT OPERATIONS

Depot maintenance is the responsibility of and is performed by designated maintenance activities (including contractor facilities) to augment stocks of serviceable materiel by overhauling and rebuilding unserviceable assets that require maintenance beyond the capabilities of general support activities. This responsibility is satisfied through a combination of more extensive shop facilities, more specialized equipment, and more highly skilled personnel than those found at lower levels of maintenance. Depot maintenance usually is accomplished in fixed shops and facilities that are Government-owned and -operated, Government-owned and contractor-operated, or contractor-owned and -operated (Ref. **6**).

Depot maintenance support demands that four essential elements be available within the same time frame. These elements are as follows:

a. Unserviceable but repairable items

b. Parts required to accomplish the repair

c. Obligational authority

d. Repair capability, including documentation, tools, test equipment, plant facilities, and manpower allocations.

The process of bringing these essentials together requires considerable coordination among individual commodity commands, agencies, and oversea commands. This process affects or is affected by other functions and programs such as planning, programming, budgeting, funding, supply control, production control, and maintenance engineering. Maintenance engineering decisions, for example, determine the materiel to be repaired at the depot and the depot repair capability.

Depot maintenance is accomplished with the assistance of technical documentation designated as depot maintenance work requirements. These are prepared for each materiel item designated for depot maintenance, and provide specific instructions for accomplishing the work, as well as additional information as follows:

a. Production line flow

b. Test, measurement, and diagnostic equipment

c. Jigs, tools, and fixtures

d. Tolerances and specifications

e. Repair parts

f. Maintenance of forms and records.

Depot pilot overhaul programs are conducted for selected materiel. Item selection is based on anticipated needs for future overhauls of materiel for which there are no validated procedures. After overhaul, statistically significant numbers of items are subjected to comprehensive tests by an agency exterior to the depot. If the results of the test are satisfactory, subsequent overhauls of the same materiel are routinely accomplished by the depot, and only normal depot test and checkout of the overhauled items are required. In addition to accomplishing the actual maintenance, the objectives of a pilot overhaul program are to (Ref. **7**):

a. Develop and validate depot maintenance procedures and standards, including quality assurance aspects.

b. Develop typical depot shop layouts, which will include inspection check points during the overhaul process.

c. Determine and validate requirements for capital equipment, jigs, fixtures, special tools, inspection gages, and calibration equipment necessary to support the reconditioning program.

d. Insure that appropriate drawings and specifications for tools and/or equipment requiring depot fabrication or procurement are developed on a timely basis.

e. Develop repair part consumption data for follow-on overhaul programs.

f. Develop overhaul costs based on repair parts, components, and assemblies required and man-hours expended.

g. Provide depot maintenance personnel with practical experience in performing equipment overhaul.

h. Confirm the requirements for on-the-job and formal school training of maintenance personnel.

i. Provide sufficient maintenance experience and assemble a data package to permit depot-type overhaul under commercial contract.

j. Evaluate the overhauled product on the basis of preproduction or initial production testing criteria.

Basically, depot maintenance requirements are determined by considering serviceable assets in the worldwide inventory, projecting losses, and deciding how the deficiency will be overcome; i.e., by overhaul or by new procurement. Overhaul is used only to restore economically repairable unserviceables to a serviceable condition. All other deficiencies are covered by new procurement.

To standardize all aspects of materiel management, including depot management, the Army Materiel Command has instituted a computer oriented data system that is designated the national automatic data program for AMC logistic management. The portion of this program applicable to depot management is called SPEEDEX, which is the acronym for System-wide Project for Electronic Equipment at Depots, Extended. The primary objectives of the program are to use the data to improve mission capabilities, attain improved efficiency, and reduce costs (Ref. 5).

2-7 DISPOSAL

The disposal phase begins when end items or systems have been declared obsolete and are no longer suitable for use by U.S. Army units. The phase ends when the item is removed from the inventory. Normally, the planning for phaseout of materiel is initiated following the approval of a development plan for materiel that will supplant the materiel in use. The phasein schedule for new materiel largely determines the timing and composition of phaseout planning documents, although factors such as obsolescence, reliability, maintainability, and cost to repair may result in an accelerated phaseout schedule.

Because of the distinct support implications of materiel phaseout, the preparation of technical criteria for the phaseout and disposal plan is a maintenance engineering responsibility, and the plan normally is administered by a commodity command. The latter has responsibility for planning support for the phasein of new materiel and for the orderly phaseout of materiel being replaced. The phaseout of equipment requires extensive coordination. The activity responsible for preparation of the materiel phaseout and disposal plan must coordinate the phaseout schedule with all interested activities to minimize accumulation of excess materiel requiring subsequent disposal action.

Materiel phaseout affects all categories of materiel support resources, and the scheduling of phaseout requires examination of each category as a separate entity. The following are representative phaseout actions applicable to the support resources of materiel programs:

a. Adjust or curtail programming, budgeting, funding, and procurement for acquisition of support resources.

b. Identify repair part stock numbers and personnel skills to be affected by end item phaseout.

c. Revise the maintenance concept and standards within applicable categories of maintenance to conform to the phaseout schedule for the end item.

d. Reflect the phaseout schedule in applicable supply control studies to permit proper allocation of existing assets to other materiel programs. Revise requisitioning objectives as appropriate.

e. Establish special criteria for controlled cannibalization and economic repairability as may be necessary.

f. Adjust field and depot modification programs to satisfy known operational requirements.

g. Adjust training programs, qualitatively and quantitatively, to meet only project needs. This consideration includes maintenance and supply skills for civilian and military personnel at all levels of activity; it also includes technical assistance activities.

h. Control additional printing and revision of equipment publications.

i. Establish demilitarization procedures and establish schedules for demilitarization, as appropriate.

j. Advise all interested agencies of phaseout schedule.

Materiel still in operational use during the phaseout period is supported in accordance with existing directives and publications. However, some support plans may require modification in order to permit an orderly and economic phaseout without deterioration of the required readiness condition; for example, cannibalization may be used in accordance with type reclassification actions in the later part of the phaseout program.

When materiel (support equipment and repair parts) is scheduled for phaseout, revised equipment distribution plans are sent to losing commands for their determination of excess assets. A survey is then conducted to determine which other commands or agencies can use the assets. Assets for which there is no further use are type classified obsolete, and disposition instructions are sent to the losing commands. The instructions include shipping instructions for assets having further application, and disposal instructions for those declared obsolete.

Disposal of an item for which there is no Army use may be by donation, sale, destruction, or abandonment. Competitive, negotiated, or retail sales are used, depending upon the quantity and value of the obsolete assets. Special support equipment that is lethal or has security or Government recognized proprietary restrictions must be demilitarized prior to disposal.

A special case of disposal involves the transfer of obsolete materiel to military assistance programs countries. In such cases, it may be necessary for the Army to maintain a support capability even though none of the prime materiel remains in the Army inventory. For example, the receiving country is likely to require training assistance for a limited time and could require replenishment repair parts and depot overhaul assistance for an extended period of time.

The disposal of personnel and technical publications is straightforward. As units are inactivated, their operational and support personnel are trained, as required, and given new assignments. Frequently, many of these personnel are assigned to materiel units that are replacing those being phased out. Publications are destroyed if they have no further use. If they can be used elsewhere, such as by an allied power, they are redistributed. In either event, historical copies are retained. All other support resources except facilities can be phased out with little difficulty. Facilities are treated much like materiel, and are either diverted to new uses or are sold.

REFERENCES

1. AR 1000-1, *Basic Policies for Systems Acquisition by the Department of the Army,* 30 June 1972.
2. AR 70-27, *Development Plan/Development Concept Paper/Program Memorandum,* 21 February 1973.
3. AR 750-37, *Sample Data Collection, The Army Maintenance Management System (TAMMS),* 24 March 1971.
4. AMCR 750-3, *Control of Equipment and Maintenance Improvement; Preparation of Equipment Improvement Report and Maintenance Dzgest,* 22 April 1970.
5. FM 38-5, *Logistics Maintenance Management,* May 1969.
6. AMCP 700-10, *Dzgest of Depot Operations Policies,* May 1972.
7. AMCR 750-7, *Depot Maintenance Pilot Overhaul and Recondition Testing,* 2 September 1965.

BIBLIOGRAPHY

DoD Directive 4100.35-G, *Integrated Logistic Support Planning Guide for DoD Systems and Equipment,* October 1968.

DA LOI, *Letter of Instructions (LOI) for Implementing the New Materiel Acquisition Guidelines,* 23 August 1972.

AR 750-1, *Army Materiel Maintenance Concepts and Policies,* May 1972.

CHAPTER 3
MAINTENANCE ENGINEERING INFLUENCE ON DESIGN

This chapter discusses why, when, and how maintenance engineering influences materiel design. Virtually all of the design considerations that impact maintenance are addressed. Among these are reliability, safety, durability, redundancy, maintainability, and human factors. The advantages and disadvantages of various design approaches are described, and advice is given on sources of data with which to evaluate design.

3-1 INTRODUCTION

During the initial stage of a materiel acquisition program, planners are faced with one constant and two variables. The constant is operational requirements. The variables are materiel design concepts and support subsystem concepts. Usually, there are several combinations of design and support that will satisfy operational requirements. A major maintenance engineering function at this time is to influence design so that the optimum design-support combination results. This is the combination that satisfies operational requirements at lowest life cycle cost.

The problem is complex, but not impossible. Operational requirements, historical data, and judgment normally permit the elimination of all except a very few design-support combinations, and these are then subjected to quantitative comparisons. Historical data and judgment are augmented-with assumed quantitative ranges for reliability and maintainability, and gross cost trade-offs are performed to determine the most economical design-support combination. Where appropriate, human factor and safety design requirements also are evaluated and established by the trade-offs.

The products of the trade-offs, which, of course, are conducted in concert with the other engineering disciplines, are baseline design and support requirements at the end item level, and a companion support concept. Multiple reliability values ranging between those desired and those required may be stated. Maintainability requirements are fundamental, specifying basic requirements such as built-in test equipment, modular packaging, and average times for corrective and preventive maintenance. The support concept is also fundamental, and support resource requirements are defined only grossly.

As the materiel program evolves, refined design information enables refinement of support requirements and identification of more specific design requirements. For example, an initial requirement for modular packaging with modules to be repaired at the depot might evolve as a requirement for modules to be discarded at failure. Also, maintenance engineering assures that materiel design and the support concept are continuously in harmony—complementary rather than contradictory.

. Maintenance engineering can never relax its vigilance with regard to design. It can never be assumed that design is firm and optimum because, with or without maintenance engineering requirements, design details will change during all materiel program phases, including production. Every change must be analyzed to determine its impact on support, and to determine whether or not the change generates a maintenance engineering requirement for additional design changes.

Fig. **3-1** is a simple model that graphically portrays the foregoing discussion. The model is independent of materiel program phases. It shows that design and support alternatives first are evaluated qualitatively, and that selected combinations are quantitatively compared. The model shows that, in general, operational requirements, deployment quantities, and all design features contribute to the quantity of corrective and preventive maintenance actions that must be performed. The support concept and materiel maintainability features determine the resources required to accomplish the total maintenance workload. These, of course, are the summation of the resources required at all maintenance levels envisioned by the support concept.

3-2 MAINTENANCE ENGINEERING DESIGN PHILOSOPHIES

The first and most critical task of support development is the establishment of materiel

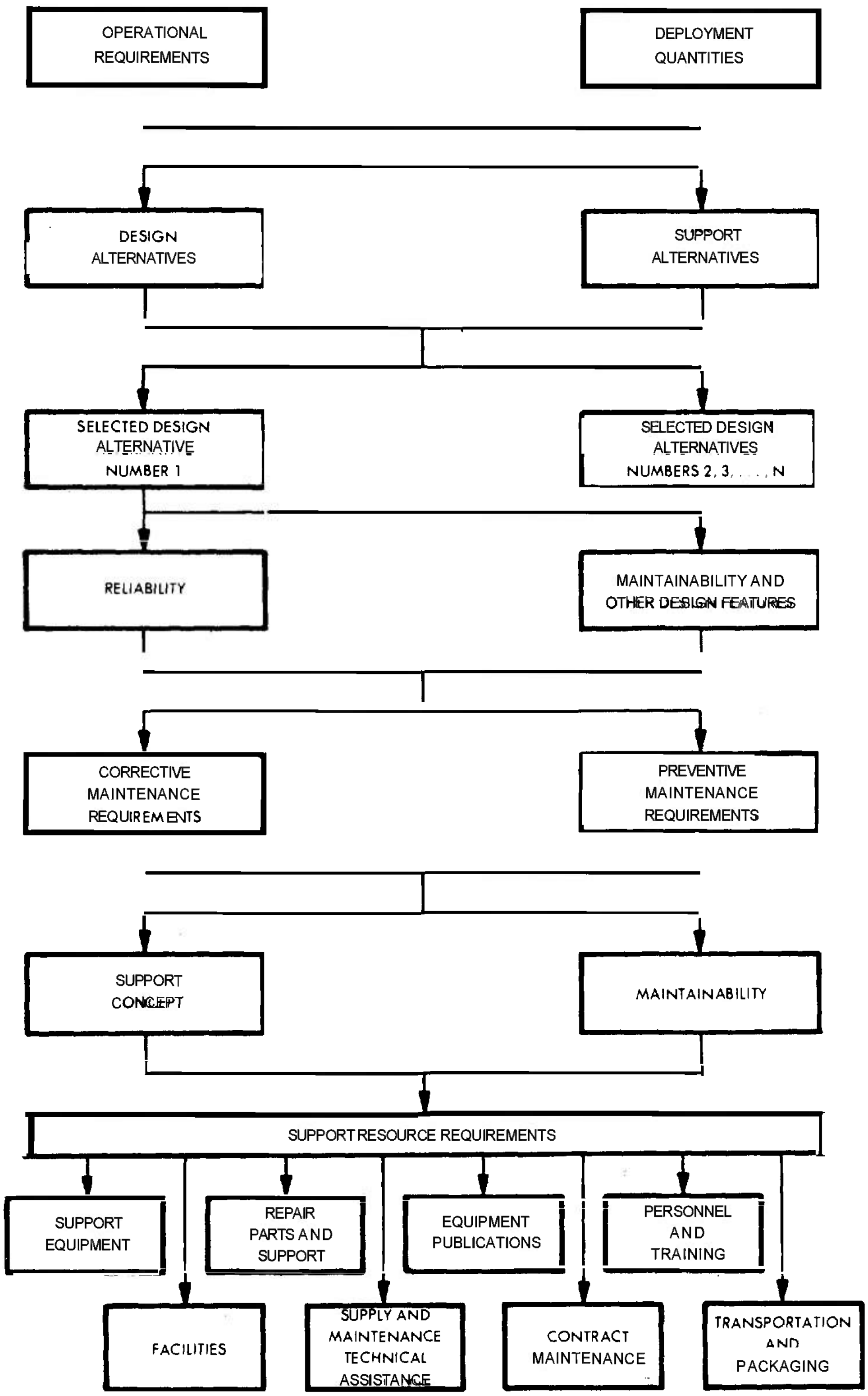


Figure 3-1. Maintenance System Model

reliability and maintainability parameters as design objectives. Maintenance engineering participates with reliability and maintainability engineers in the establishment of these objectives. The responsibility of maintenance engineering is to insure that the established reliability and maintainability parameters will result in the attainment of operational requirements at lowest life cycle cost. Depending upon the nature of the materiel, maintenance engineering also establishes requirements for design features pertaining to safety, human factors, and transportability.

The other engineering disciplines, except maintainability, are primarily oriented toward satisfying operational requirements, and look to maintenance engineering and maintainability for design guidance on characteristics that enhance materiel support. Since maintenance engineering is the only discipline functionally aware of the full impact of design features on support, it follows that it is in the best position to identify design features that enhance support. Aggressive accomplishment of this role is the keystone to an effective maintenance engineering program.

Many design features that enhance materiel support increase acquisition costs. This is not a deterrent to establishing and justifying the features as requirements, providing life cycle cost savings can be demonstrated. In most cases, savings can be demonstrated since it is estimated that materiel life cycle maintenance support costs are on the order of **3** to 20 times the original procurement costs (Ref. 1).In other words, the expenditure of an additional dollar on design can net from $2.00 to $19.00 in life cycle cost savings. In some cases, design changes can result in an avoidance of requirements for nonexistent resources such as skilled personnel, and a double payoff is realized.

An evaluation of the impact of a design feature on support is somewhat complicated by the interdependence of the support element resource requirements. Seldom will a feature impact resources of a single element. Sometimes, several elements will incur reduced requirements, sometimes there will be a mixture of reduced and increased requirements, and sometimes there will be several increased requirements. This points up the need for thorough, systematic analyses before acceptance or establishment of design requirements.

Before establishing design requirements, maintenance engineering must evaluate design alternatives and make selections. A few top-level design requirements can be established relatively quickly based on operational requirements, historical data, and judgment. For example, if system requirements include a minimum acceptable availability, it is not difficult to establish a range of minimum acceptable Values for mean time between failures and mean time to repair. Eventually though, trade-offs must be conducted between the two parameters, and specific design features must be established. It is difficult to move immediately to this level of detail. The problem derives from the identification of the features it is desired to evaluate, as well as from the conduct of the evaluation. The features to be considered are so numerous that, even with memory aids, some features offering significant potential payoffs might be overlooked.

Many memory aids have been devised. Some take the form of rather lengthy reliability and maintainability checklists (Ref. 1), and these are quite useful. Other aids emphasize brevity by simply listing fundamental design features such as reliability, diagnostics, mechanical and electrical packaging, and accessibility. Such aids leave too much unsaid, and should be used only by very experienced personnel. Another approach, which will be described in subsequent paragraphs, is to list desirable materiel maintenance objectives, and couple these with parameters that contribute to the attainment of the objectives.

Materiel maintenance parameters derive from materiel design. They may be expressed qualitatively or quantitatively. **A** qualitative expression, for example, is minimum maintenance downtime. The actual maintenance parameter is, of course, simply maintenance downtime, but a modifier is normally required to express the maintenance engineering requirement. The companion, first-level, quantitative expression can be one or more of the several that are normally used. One of the most common of these is mean time to repair. It is stated in terms of time, 25.5 min for example. Another is the ratio between maintenance hours and operating hours, which is stated as a fraction. Second-level, quantitative requirements state specific design features that will permit attainment of the first-level requirements.

Maintainability engineering, with inputs from maintenance engineering, is responsible for establishing second-level, quantitative requirements. The following sequence of events comprises a systematic method for accomplishing this function:

a. Identify desirable maintenance objectives and the qualitative maintenance parameters that contribute to attainment of the objectives.

b. Use operational requirements, historical data, and judgment to select parameters for further study.

c. Quantify the selected parameters to the lowest possible level and determine the impact on support resource requirements.

d. Establish quantitative design requirements.

Perhaps the one advantage that this method has over straight checklists is that it starts with a relatively limited number of quickly identified maintenance objectives, and eases into the problem rather than concurrently considering a host of maintenance parameters.

Table 3-1 lists the most important maintenance objectives and the most important qualitative parameters that contribute to attainment of the objectives. The table is universally applicable to all materiel, but it must be used with imagination, and a background of design and maintenance knowledge applicable to the materiel under consideration. For example, the design details of maintenance-free tank assemblies are not likely to duplicate the details of maintenance-free radar assemblies, and maintenance engineering must deal in details. In the interest of brevity, the table does not repeat characteristics. A maintenance-free design will contribute to attainment of all of the maintenance objectives, but this design characteristic is only listed once. All parameters that make multiple contributions are similarly treated.

It is apparent that use of the table to select quantitative parameters will lead to many trade-offs. Consider, for example, the first maintenance parameter contributing to the second maintenance objective, "rapid and positive prediction or detection of malfunction or degradation". This can be accomplished with built-in test equipment, automatic test equipment, or manual test equipment to the end item, intermediate assembly or piece part hardware level. Nine trade-offs would result if each of the three types of test equipment was evaluated for detecting failures at each of the three hardware levels. Fortunately, early in a materiel program, available data will not warrant more than evaluation of built-in test equipment and manual test equipment used to an end item or lower level. These four potential trade-offs might be further reduced by the application of operational requirements and historical data. Thus, the problem is not insurmountable. Later in the program, when final design details must be formulated, the alternatives are more limited.

3-3 MAINTENANCE ENGINEERING INFLUENCE ON RELIABILITY CONCEPTS DURING DESIGN (Ref. 2)[1]

Reliability is the probability that materiel will operate successfully for a specified period of time and under specified conditions when used in the manner and for the purpose intended. Materiel less than 100 percent reliable will experience failures that generate a requirement for corrective maintenance. Failures occur because of inherent limitations of components, the manner in which components are used in materiel, and the manner in which they are manufactured, operated, and maintained.

The paragraphs that follow analyze the basic reliability definition, discuss types of materiel failures, define inherent and operational reliability, and discuss the statistical approach to reliability.

a. Analysis of Reliability Definition. Since reliability is a probability, it is a variable and not an absolute value. If materiel is 90 percent reliable, there is a 10 percent chance that it will fail. Since failure is a chance, it may or

[1] From *Reliability for the Engineer* by Richard B. Dillard, © 1965 by Martin Marietta Corporation and reproduced with their permission.

TABLE 3-1. MATERIEL MAINTENANCE OBJECTIVES VS MAINTENANCE PARAMETERS

1. Minimize maintenance frequency by using:
   - Maintenance-free design
   - Standard and proven design and components
   - Simple, reliable, and durable design and components
   - Fail-safe features to reduce failure consequences
   - "Worst case" design techniques and tolerances that allow for use and wear throughout item life.
2. Minimize maintenance downtime by designing for rapid and positive:
   - Prediction or detection of malfunction or degradation
   - Localization to the affected assembly, rack, or unit
   - Isolation to a replaceable or repairable module or part
   - Correction by replacement, adjustment, or repair
   - Verification of correction and serviceability
   - Identification of parts, test points, and connections
   - Calibration, adjustment, servicing, and testing.
3. Minimize maintenance costs by designing for minimum:
   - Hazards to personnel and equipment
   - Depot or factory maintenance
   - Consumption rates and costs of repair parts and materials
   - Erroneous indications of failure
   - Personnel skills and quantities.
4. Minimize maintenance complexity by designing for:
   - Compatibility between materiel and support equipment
   - Standardization of design, parts, and nomenclature
   - Interchangeability of like components, material, and repair parts
   - Minimum maintenance tools, accessories, and equipment
   - Adequate accessibility, work space, and work clearances.
5. Minimize maintenance personnel requirements by designing for:
   - Logical and sequential function and task allocations
   - Easy handling, mobility, transportability, and storability
   - Minimum numbers of personnel and maintenance specialities
   - Simple and valid maintenance procedures and instructions.
6. Minimize maintenance errors by designing to reduce:
   - Likelihood of undetected failure or degradation
   - Maintenance waste, oversight, misuse, or abuse
   - Dangerous, dirty, awkward, or tedious job elements
   - Ambiguity in labeling or coding.

may not occur. To perform without failure means that failures will not occur that will keep the materiel from performing its intended mission. From this comes a more general definition of reliability: that it is the probability of success.

From the foregoing comes the fact that a definition of what constitutes the success of deployed materiel is necessary before a statement of reliability is possible. One definition of success for a missile flight might be that the missile leaves the launching pad. Another definition might be that the missile hits the target. Either way, a probability of success or reliability can be determined, but it will not be the same for each success definition. The importance of defining success cannot be overemphasized. Without it, determination of whether or not a device has met its reliability requirements is impossible.

The latter part of the definition indicates that a definition of success must specify the operating time, operating conditions, and intended use, i.e.:

(1) Operating time is defined as the time period in which the device is expected to meet its reliability requirements. The time period may be expressed in seconds, minutes, hours, years, or any other unit of time.

(2) Operating conditions are defined as the environment in which the device is expected to operate, and specifies the electrical, mechanical, and environmental levels of operation and their durations. Preventive maintenance can comprise a part of operating conditions.

(3) Intended use is defined as the purpose of the device and the manner in which it will be used. For example, a missile designed to hit targets 1000 miles away should not be considered unreliable if it fails to hit targets 1100 miles away. Similarly, a set of ground checkout equipment designed to be 90 percent reliable for a 1-hr tactical countdown should not be considered unreliable if it fails during 10 consecutive countdowns of training exercises.

b. Product Failure Modes. In general, critical equipment failures may be classified as:

(1) Catastrophic part failures – Failures that occur randomly in time and result in the sudden inability of an item to perform its function; e.g., a resistor opens or shorts.

(2) Tolerance failures – Failures that result when item parameters deviate from specified values; e.g., the resistance of a resistor drifts outside of specification limits.

(3) Wearout failures – Failures that increase with operating time and result in the gradual loss of the ability of an item to perform its function; e.g., a piston ring wears to the extent that required compression cannot be attained.

Assuming that these failure modes are independent, the expression for reliability then becomes

$$R = P_c P_t P_w \tag{3-1}$$

where

R = reliability

P_c = probability that catastrophic part failures will not occur

P_t = probability that tolerance failures will not occur

P_w = probability that wearout failures will not occur

c. Inherent Product Reliability. To consider the inherent reliability of materiel, think of the expression $P_c P_t P_w$ as representing the potential reliability of the item as described by documentation. Or to put it another way, let it represent the reliability that is inherent in the paper design instead of the reliability of the manufactured hardware. If the inherent reliability of the design is denoted by R_i, then

$$R_i = P_c P_t P_w \tag{3-2}$$

An expression for R_i is of interest, because R_i represents a potential reliability that can never be increased except by a design change. Actually, it cannot even be achieved, because this would require perfect execution of all functions required to translate a drawing-board design into operating hardware and of subsequent operational and maintenance functions.

d. K-factors. K-factors have values between 0 and 1, and represent probabilities that designated functions will be performed properly. The factors are used to calculate the reliability of deployed materiel as follows:

$$R_o = R_i\ (K_q K_m K_r K_l K_u) \qquad (3\text{-}3)$$

where

R_o = operational reliability

R_i = inherent reliability

K_q = probability that quality test methods and acceptance criteria will not degrade inherent reliability. An example of K_q is the situation in which a defective part is accepted and later appears as a field failure and is counted against product reliability.

K_m = probability that manufacturing processes, fabrication, and assembly techniques will not degrade inherent reliability. Examples of K_m would be cold solder joints, poor lamination of multilayer printed circuit boards, loose fittings in plumbing installations, and many others, which can appear as field failures.

K_r = probability that reliability activities will not degrade inherent reliability. An example of K_r would be an inaccurate test analysis that forces a design change that degrades rather than improves the hardware performance.

K_l = probability that logistic activities will not degrade inherent reliability. An example of K_l would be an inaccurate procedure in a repair manual, which, if followed, would create more failures than it fixes.

K_u = probability that the user will not degrade inherent reliability. An example of K_u would be an operator error that causes a field failure because correct operating procedures are not followed.

There are many other K-factors that could be considered, but these are the main ones. Operational reliability is degraded by each of these factors that is less than 1, and becomes 0 if any factor becomes 0.

3-3.1 STATISTICAL APPROACH TO RELIABILITY

Reliability is defined as a probability. Therefore, to effectively influence design reliability, maintenance engineering must have an understanding of the fundamentals of probability theory.

3-3.1.1 Probability Defined

Probability is often referred to as the probability of success. This can be defined as follows:

If an event can occur in A different ways, all of which are considered equally likely, and if a certain number B of these events is considered successful or favorable, then the ratio B/A is called the probability of success.

Probability by this definition is also called an *a priori* (beforehand) probability, because its value is determined without experimentation. It follows that reliability predictions of what the probability of success of missile flights will be before they occur are *a priori* reliabilities. In other words, *a priori* reliabilities are estimates of what may happen, not observed facts.

After an experiment has been conducted, an *a posteriori* probability or an observed reliability can be defined as follows:

If $f(n)$ is the number of favorable or successful events observed in a total number of n trials or attempts, then the relative frequency $f(n)/n$ is called the statistical probability, the *a posteriori* probability, the empirical probability, or the observed reliability.

Note that the number of favorable events $f(n)$ is a function of the total number n of trials or attempts. Therefore, as the number of trials or attempts changes, $f(n)$ may also change, and, consequently, the statistical probability or observed reliability may change.

3-3.1.2 Probability Theorems

Three probability theorems are presented. In these theorems and examples, the probability of success (reliability) is represented by R, and the probability of failure (unreliability) by Q.

a. Theorem 1. If the probability of success is R, then the probability of failure Q is equal to $1 - R$. In other words, the probability that all possible events will occur is

$$Q + R = 1 \tag{3-4}$$

Example: If the probability of a missile flight success is 0.81, the probability of flight failure is 1 − 0.81 = 0.19. Therefore, the probability that the flight will succeed or fail is 0.81 + 0.19 = 1.0.

b. Theorem 2. If R_1 is the probability that a first event will occur, and R_2 is the probability that a second independent event will occur, then the probability that both events will occur is

$$R = R_1 R_2 \tag{3-5}$$

A similar statement can be made for more than two *independent* events.

Example: If the probability of completing one countdown without a failure R_1 is 0.9, the probability of completing two countdowns without failure is $R_1 R_2 = 0.9 \times 0.9 = 0.81$. The probability that at least one of the two countdowns will fail is $1 - R_1 R_2 = 1 - 0.81 = 0.19$ (from Theorem 1). At least one will fail because the unreliability term Q includes all possible failure modes, which in this case is two: one or both countdowns fail.

c. Theorem 3. If the probability that one event will occur is R_1 and the probability that a second event will occur is R_2, and if not more than one of the events can occur (i.e., the events are *mutually exclusive),* the probability that either the first or second event, not both, will occur is

$$R = R_1 + R_2 \tag{3-6}$$

A similar theorem can be stated for more than two events.

Example: Consider the probability of completing two countdowns without a failure. Let the probability of success for the first and second countdowns be R_1 and R_2, and the probabilities of failure be Q_1 and Q_2. To solve the problem using Theorem 3, it is best to diagram the possible events as shown in Fig. 3-2.

The mutually exclusive events are:

Q_1, first countdown fails; $R_1 Q_2$, first countdown succeeds and the second fails; and $R_1 R_2$, both countdowns succeed.

From Theorem 3, the probability that one of the three events will occur is

$$Q_1 + R_1 Q_2 + R_1 R_2.$$

But since these three events represent all possible events that can occur, their sum equals 1 (from Theorem 1). Therefore,

$$Q_1 + R_1 Q_2 + R_1 R_2 = 1.$$

$R_1 R_2$, the probability of completing both countdowns without one failure, is the solution to the proposed problem; therefore,

$$R_1 R_2 = 1 - (R_1 Q_2 + Q_1)$$

If $R_1 = 0.9$, $Q_1 = 0.1$, $R_2 = 0.9$, and $Q_2 = 0.1$, then,

$$\begin{aligned} R_1 R_2 &= 1 - [(0.9)(0.1) + 0.1] \\ &= 1 - [0.09 + 0.1] \\ &= 1 - 0.19 \\ &= 0.81 \end{aligned}$$

which agrees with the answer in the example in Theorem 2.

3-3.1.3 Exponential Distribution

The term $e^{-\lambda t}$ is called the exponential distribution and is the simplest form of P_c, the

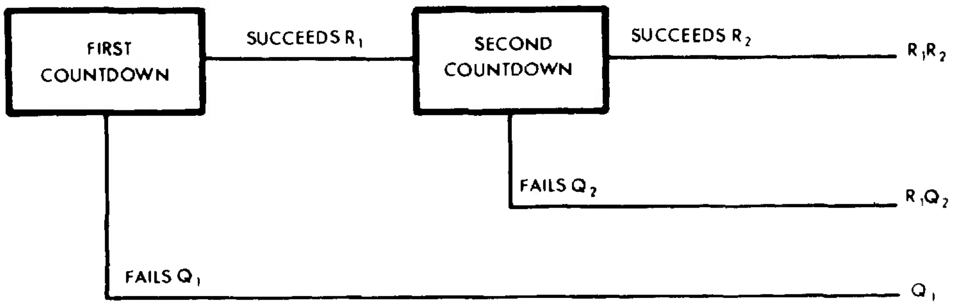


Figure 3-2. Possible Events Diagram—Probability of Completing Two Countdowns Without a Failure

probability that a catastrophic part failure will not occur.

$$P_* = e^{-\lambda t} \tag{3-7}$$

In this expression, λ is a failure rate for random catastrophic part failures that occur in such a short period of time that they cannot be prevented by preventive maintenance. Operating time is designated by t. Random catastrophic failures are failures that occur randomly in time and from part to part.

For example, suppose a contractor uses one million integrated circuits in a computer. Over a period of time, he may observe an average of one circuit failure every 100 operating hours. Even though he knows this failure rate, he cannot say which one of the million circuits will fail. All he knows is that, on the average, one will fail every 100 hr. In fact, if a failed circuit is replaced with a new one, the new one, theoretically, has the same probability of failure as any other circuit in the computer. In addition, if he performs a failure analysis on each of the failed circuits, he may find that every failure is caused by the same mechanism, such as poorly welded joints. Unless he takes some appropriate corrective action, he will continue to observe the same random failures even though he knows the failure cause.

A catastrophic failure will be defined as an electrical open or short, a mechanical or structural defect, or an extreme deviation from an initial setting or tolerance. (A 5 percent tolerance resistor that deviated beyond its end-of-life tolerance, to 20 percent for example, would be considered to have failed catastrophically.)

The latter portion of the failure rate definition refers to the circumstance under which a failure is revealed. If a potential operating failure is corrected by a maintenance function, such as scheduled preventive maintenance, where an out-of-tolerance part could be replaced, then that replacement cannot be represented by λ, since it did not cause an operating or unscheduled failure. Here we see one of the many variables that affects the operating failure rate of a product: the maintenance philosophy.

3-3.1.4 The "Bathtub" Curve

In the exponential distribution, λ was referred to as an average failure rate, indicating that λ may be a function of time, $\lambda(t)$. Fig. 3-3 shows three general curves representing $\lambda(t)$ possibilities.

Curve A of Fig. 3-3 shows that as operating time increases, failure rate also increases. This type of failure rate is found where wearout or age is a dominant stress (for example, slip clutches or automobile tires).

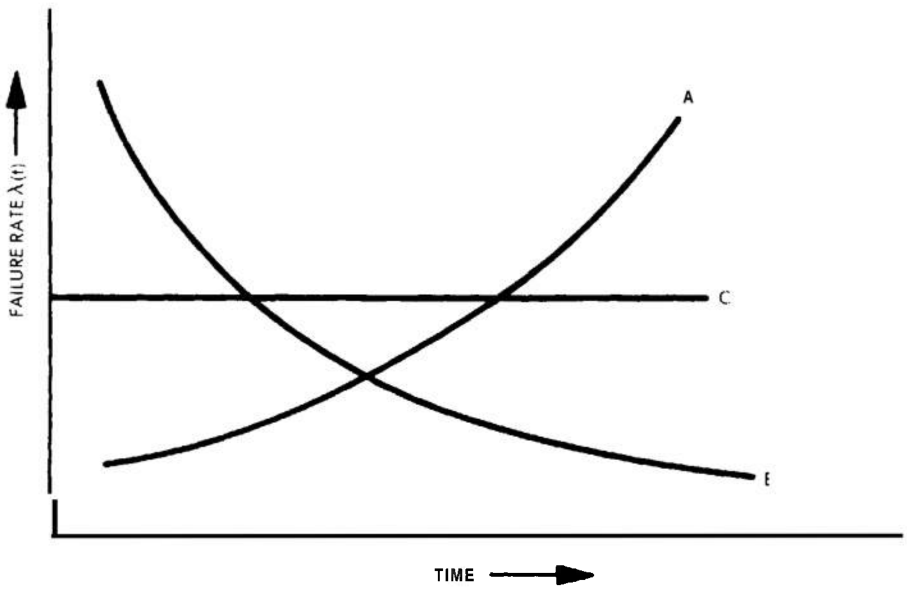


Figure 3-3. Failure Rate Curves

Curve B shows that as operating time increases, the failure rate decreases. This type of failure rate has been observed in some electronic parts, especially semiconductors.

Curve C shows that as operating time increases, the failure rate remains constant. This type of failure rate has been observed on many complex systems and subsystems. In a complex system (i.e., a system with a large number of parts), parts having decreasing failure rates reduce the effect of those having increasing failure rates. The net result is an observed constant failure rate for the system. Because of this, part failure rates are usually given as a constant, although in reality they may not be.

In this discussion, only constant part failure rates will be considered because these rates will be related to system operation.

If, for a typical system or complex subsystem, the failure rate was plotted against operating life, a curve as shown in Fig. 3-4 would result. The curve is commonly referred to as the "bathtub" curve. This curve is explained in the following paragraphs.

a. Infant Mortality. The time t_0 represents the time that the system is first put together.. The interval from t_0 to time t_1 represents a period during which assembly errors, defective parts, and compatibility problems are found and corrected. As shown, the system failure rate decreases during this debugging or burn-in interval as these gross errors are eliminated.

b. Useful Operating Life. The interval from time t_1 to t_2 represents the useful operating life of the equipment and is characterized by a constant failure rate. It is during this period of time that the expression for $P_c = e^{-\lambda t}$ is valid. Therefore, when $e^{-\lambda t}$ is used, it is assumed that the system has been properly debugged. In practice, this assumption may not be true, but an adequate picture of the expected operating reliability can still be obtained by accepting the assumption.

c. Wearout Period. The interval from t_2 to t_3 represents the wearout period during which age and deterioration cause the failure rate to increase and render the system inoperative or extremely inefficient and costly to maintain.

3-3.1.5 System Reliability Model

To find the reliability for a complete system, begin by developing a model for the system, writing the equation for the probability

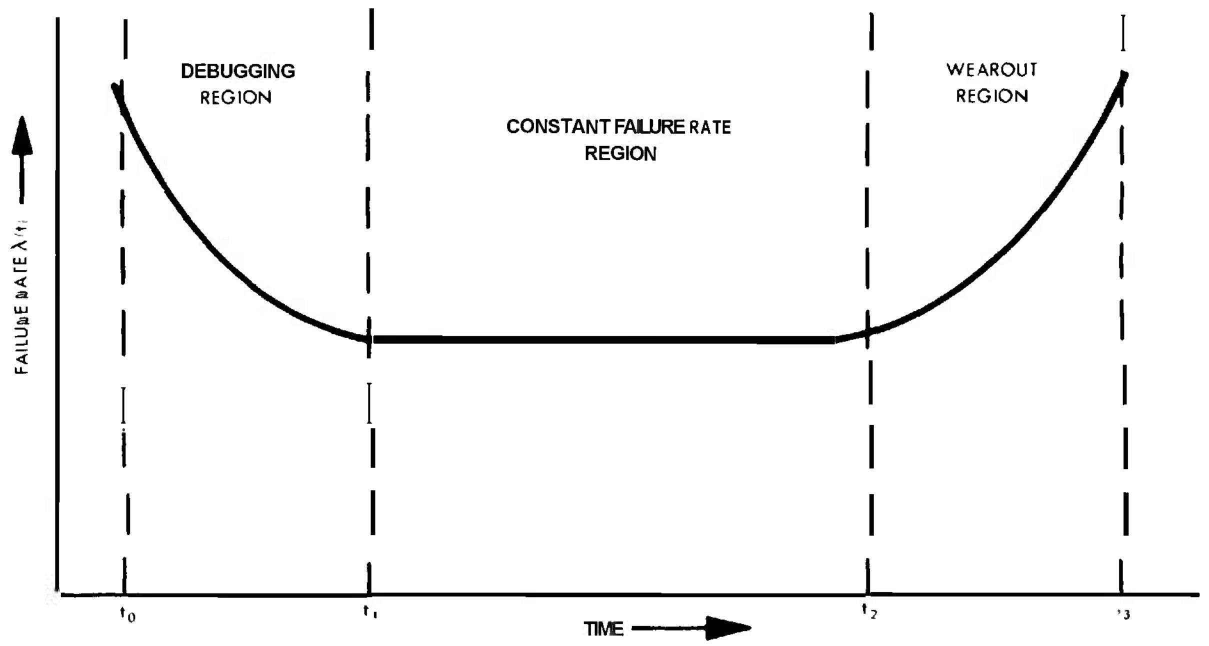


Figure 3-4. Failure Rate vs Operating Time life

of success from the model, and then using the failure rates and operating times of the system elements to calculate the reliability of the system.

Example: Consider the system model, with series and redundant elements, shown in Fig. 3-5.

The equation can be written directly as

$$R_s = R_1 R_2 R_3 [1 - Q_4 Q_5 Q_6] \quad (3\text{-}8)$$

where

R_s = system reliability

$R_1 R_2 R_3$ = probability of success of the series parts

$[1 - Q_4 Q_5 Q_6]$ = probability of success of the three parts in simple redundancy.

If it is known that

$R_1 = 0.99 = e^{-0.01}$

$R_2 = 0.999 = e^{-0.001}$

$R_3 = 0.95 = e^{-0.051}$

$R_4 = R_5 = R_6 = 0.89$

where

R_s may represent $e^{-\lambda t}$, inherent reliability R_i or observed product reliability, depending upon the stage of product development, then

$$
\begin{aligned}
R_s &= e^{-0.01} e^{-0.001} e^{-0.051} \\
&\quad \times [1 - (1 - 0.89)(1 - 0.89)(1 - 0.89)] \\
&= e^{-0.062} [1 - (0.11)(0.11)(0.11)] \\
&= e^{-0.062} [1 - 0.0013311 \\
&= e^{-0.062} (0.99867) \\
&= 0.94
\end{aligned}
$$

which is the reliability of the system. However, this does not mean that there will be no equipment failures. The system will still succeed even though one or two of the redundant paths have failed.

3-3.1.6 What Maintenance Engineering Can Do

The maintenance burden of fielded materiel varies inversely to its operational reliability. Maintenance engineering can favorably influence this reliability—which is a function of inherent reliability and K-factors—by several actions, some of the most important of which are:

a. Maintain a working knowledge of the theory of reliability and the manner in which a reliability program is conducted for a materiel program; i.e., specification requirements, initial allocation, predictions, and iterative prediction updates.

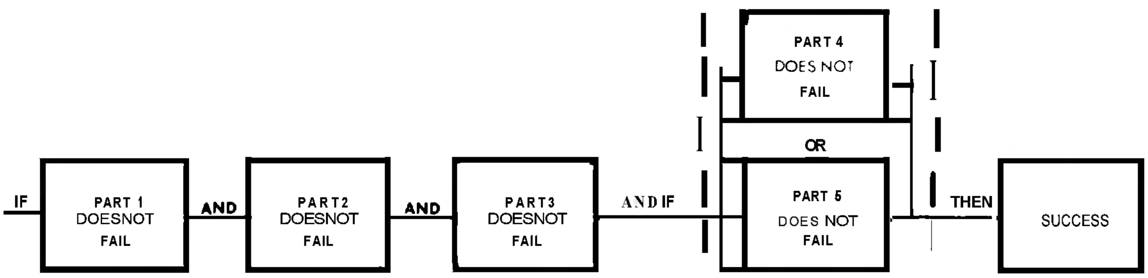


Figure 3-5. Model of System With Series and Redundant Elements

b. Based on historical data, recommend components and assemblies that have proved to be reliable, and oppose those that have been unreliable.

c. Know the facts and assumptions upon which failure rate data are based, and evaluate these rates and any K-factors that have been applied by using historical data. Gain management acceptance of realistic K-factors.

d. Using realistic failure rates, conduct trade-offs between improved materiel reliability and decreased maintenance costs.

e. Carefully control maintenance engineering analysis and other activities that impact the K-factors pertaining to logistic and user activities.

3-4 MAINTENANCE ENGINEERING INFLUENCE ON LIFE CYCLE LOGISTICS

In its broadest sense, logistics comprises "those aspects of military operations which deal with: (a) design and development, acquisition, storage, movement, distribution, maintenance, evacuation and disposal of materiel; (b) movement, evacuation, and hospitalization of personnel; (c) acquisition or construction, maintenance, operation, and disposition of facilities; and (d) acquisition or furnishing of services" (Ref. 3). Maintenance engineering significantly influences the manner in which the majority of these functions is performed by participating in some and by establishing requirements that define the scope of others.

Table 3-2 shows how maintenance engineering activities interface with the logistic functions. It may be seen that as maintenance engineering 'establishes design and support resource requirements for materiel, it is concurrently establishing requirements that must be satisfied by a military logistic system, either the one in being, or a modified version. New materiel with logistic requirements compatible with the current logistic system can be phased economically and efficiently into the inventory. The converse is true for new materiel with incompatible logistic requirements. Such requirements should be avoided unless overwhelming operational or economical advantages can be demonstrated.

3-4.1 COST TRADE-OFFS

A trade-off is a comparison of competing system characteristics and factors to determine the optimum overall combination. Simply stated, it is a comparison of two or more ways for arriving at a goal for the purpose of making a decision. Trade-offs of varying complexity are conducted throughout the life cycle of materiel. The primary purpose of a maintenance engineering cost trade-off is to select the materiel design and support concepts that satisfy operational requirements at lowest life cycle cost.

The life cycle costs associated with alternative concepts are composed of three major cost categories: research and development, acquisition, and operation and support. The first two cost categories occur only once in a materiel life cycle, but the third recurs annually for as many years as the materiel is in the operational inventory. Operating and maintenance costs normally have a dramatic effect on design decisions due to their recurring nature, and maintenance engineering uses its knowledge of. these costs to guide design properly.

A simplified example will be used to demonstrate the foregoing. Assume that a helicopter-launched antitank missile is being developed to be deployed in five separate locations. Operational requirements dictate that missile maintenance be performed by a direct support unit at each location, and at a depot, each of which has general-purpose test equipment that can be adapted for missile maintenance. Studies have demonstrated that the only other test equipment which feasibly can satisfy operational as well as depot requirements is an automatic, special-purpose test set. Missile costs are not affected by test set selection. The problem is to determine which test set is most cost-effective.

The alternatives having been established, the next step is to accrue costs. To make the point of this example, the adapters required for the general-purpose test set are assumed to be unusually expensive, and are estimated to cost $300,000 to develop and $30,000 each to procure. Special-purpose test equipment only costs half as much in each case. Suppose also that initial repair parts cost $20,000 for the adapters and $10,000 for the special-purpose test sets.

TABLE 3-2. MAINTENANCE ENGINEERING/LIFE CYCLE LOGISTIC INTERFACES

Logistic Function	Maintenance Engineering Interface
Materiel:	
Design and development	Influence design.
Acquisition	Provide basic provisioning data.
Storage	Establish packaging, handling, and facility requirements.
Movement	Establish transportation requirements.
Distribution	Establish use locations for support equipment and repair parts.
Maintenance	Establish all requirements that impact the performance of maintenance.
Evacuation	Establish requirements relevant to maintenance.
Disposal	Establish technical criteria.
Personnel:	
Movement	Establish training and maintenance locations to which personnel are moved.
Evacuation	None.
Hospitalization	None.
Facilities:	
Acquisition or construction	Establish maintenance and storage facility requirements.
Maintenance	Establish maintenance requirements for real property installed equipment.
Operation	Establish policies for operating maintenance and storage facilities.
Disposition	Identify underused maintenance and storage facilities.
Services:	
Acquisition or furnishing	Establish requirements for supply and maintenance technical assistance and for contract maintenance.

Assume that there are no other significant differences between development and acquisition costs for the two items.

Turning now to operating and support costs, and assuming 10 years of operation, repair part replenishment costs for the adapters total $10,000, and for the special-purpose test set, $5,000. The only other significant operating cost difference derives from personnel requirements. Personnel assigned to the direct support units can use the general-purpose test sets and adapters, and accomplish the missile work load with no personnel augmentation. Assignment of the special-purpose test sets to the units will necessitate the addition of one E-5 to each location. No additional personnel will be required at the depot, regardless of the test set used. Annual personnel costs are $14,300 per individual, a figure that includes basic pay and personnel support costs (Ref. 4).

Trade-off results are shown in Table 3-3. Clearly, the general-purpose test equipment is the best choice, and the choice is forced by the seemingly insignificant addition of one individual to five maintenance locations. Personnel will generally be found to be the most costly

TABLE 3-3. COST TRADE-OFF OF GENERAL-PURPOSE TEST EQUIPMENT VS SPECIAL-PURPOSE TEST EQUIPMENT FOR HYPOTHETICAL MISSILE

Cost Source	General-purpose Test Equipment (Adapters)	Special-purpose Test Equipment
Development	$300,000	$150,000
Procurement		
Basic items	180,000	90,000
Repair parts	20,000	10,000
Operation and support (10 years)		
Repair parts	10,000	5,000
Personnel	------	715,000
	$510,000	$970,000

of all of the support resources. Since skilled personnel also are limited in quantity, it is of particular importance to influence design to minimize qualitative and quantitative personnel requirements.

3-4.2 TOOLING REQUIREMENTS

The typical materiel program generates requirements for numerous varieties and sizes of standard tools, and for a lesser number of special tools. The latter comprises tools that are designed and produced to satisfy materiel maintenance requirements that cannot be satisfied by tools that are in the military or commercial inventory. In its broadest sense, the word "tools" implies both hand tools and shop tools. This discussion will be limited to hand tools, but some of the principles stated apply to all tooling.

The varieties and sizes of hand tools required depend upon materiel design. For example, each type of fastener, other than manually operated fasteners, generates a requirement for a tool type. The number of required tool sizes within this type depends in turn upon the number of size variations within the fastener type. Torquing requirements for various size fasteners generate another range of tool requirements, as do torquing values that do not lie within the range of a single tool. Limited accessibility usually generates requirements for an additional range of tool varieties and sizes. The cumulative effects of these and other materiel design features are organizational maintenance personnel with bulging tool kits and field maintenance personnel with bulging shop vans.

A reduction in tool requirements for a materiel program will result in cost savings and increased maintenance efficiency. The cost savings are self-evident since each tool costs something; reduce the number and thereby reduce the cost. The costs involved in a special tool are more than are generally realized. Here, one encounters design, development, and documentation costs, test costs, procurement costs, and a recurring supply management cost. The latter cost accrues when a new line item is introduced into and maintained in the supply system. Assuming a 10-year life cycle, this cost alone will approximate $9,000. Add this to the previously mentioned costs and a seemingly inexpensive special tool takes on significant life cycle costs.

The impact of tool quantities on maintenance efficiency also is not generally realized. A simple example will demonstrate this. A maintenance technician will normally select the proper tools to initiate a maintenance task, which frequently is access to a suspected area of trouble. If subsequent troubleshooting leads to a requirement for additional access, and the tools in hand are not the proper ones, he should go back to the tool kit. However, he is more likely to make do with what he has immediately available. This can result in maintenance damage. On the other hand, even if he does return to a tool kit containing a variety of sizes of the same type tool, he may still select the wrong one, and damage can still result.

Maintenance engineering can control tool requirements by influencing design. At the start of a materiel program, establish generalized requirements for a minimum number of standard fasteners, adequate accessibility, and a minimum number of special tools. As design progresses, monitor attainment of these goals through maintenance analyses. Challenge, in particular, special tool requirements. Determine how similar maintenance was performed on other materiel, and the designs that permitted the use of standard tools. Survey standard and commercial tools. Accept special tools only as a last resort.

A true incident will demonstrate the importance of verifying that a special tool is actually required. On a particular system, there was an organizational maintenance requirement to replace large gaskets. The nature of the task required that the adhesive be spread with a gun similar to a caulking gun. Design engineering initiated the design of a special tool, and tested a preliminary concept, which performed marginally. Meanwhile, maintenance engineering made a survey of existing standard and commercial equipment, and found a commercial gun costing about $5.00, which, when procured, performed perfectly. Design effort was stopped, with a resulting life cycle savings of at least $10,000. Compared to materiel life cycle costs, this savings is insignificant. However, multipled by 25 incidents, it amounts to a quarter of a million dollars, and there are certainly more than this number of opportunities in the average materiel program to realize similar savings.

3-4.3 ENVIRONMENTAL COMPATIBILITY (Ref. 1)

The global mission of the Army dictates that its materiel be capable of surviving, operating, and being maintained in a variety of natural and induced environments. A natural environment is comprised of the climate, atmosphere, and terrain in a geographical location. An induced environment is a combination of the effects of personnel and materiel functions, such as the shock and vibration resulting from transportation and handling, or temperatures resulting from equipment operation. Regardless of materiel design, maintenance requirements will be greater in extreme environments than in normal environments. However, this differential can be reduced by proper design, and a maintenance engineering function is to insure that this design is achieved. The following discussion will identify the most significant environmental parameters and briefly describe the failures they cause, and proper maintenance engineering actions with regard to design. See Refs. 14-18 for a detailed discussion of environmental factors.

3-4.3.1 Natural Environments

Operation and maintenance problems in extremely cold climates are caused mainly by drifting snow and low temperatures. Tracked vehicles must be used for travel off the road. Drifting snow can enter a piece of equipment and either impede its operation, or melt and then refreeze inside as solid ice. Then, when the unit generates heat, the melted snow will cause short circuits, form rust, or rot organic materials.

The subzero temperatures may produce the following effects: volatility of fuels is reduced; waxes and protective compounds stiffen and crack; rubber, rubber compounds, plastics, and even metals in general lose their flexibility, become hard and brittle, and are less resistant to shock. At a temperature of −30°F, batteries are reduced in current capacity by 90 percent and will not take an adequate charge until warmed to 35°F. The variations in the capacitance, inductance, and resistance of electrical components and parts can become so great as to require readjustment of critical circuits.

The high day temperatures of the desert, solar radiation, and dust and sand, combined with sudden violent winds and large daily temperature fluctuations, may create many of the following maintenance problems: heat can lead to difficulties with electronic and electrical equipment, especially if these have been designed for moderate climates; materials such as waxes soften, lose strength, and melt; material may lose mechanical or electrical properties because of prolonged exposure; fluids may lose viscosity; and joints that would be adequate under most other conditions may leak. Heat also can cause the progressive deterioration of many types of seals in transformers and capacitors. Capacitors of some types develop large and permanent changes in capacity when exposed to temperatures above 120°F. Finally, tires wear out rapidly; paint, varnish, and lacquer crack and blister; objects exposed to solar radiation become so hot that they cannot be handled without protection for the hands; and equipment is apt to be damaged by sand and dust.

The tropical environment comprised of high temperature and excessive humidity leads al! other environments in its destructive effect on materiel. This environment encourages and accelerates the growth of fungi and bacteria, and the corrosion process. The physical strength and electrical properties of materials are affected adversely, and the actual functional performance of materiel is impaired.

Salt air and salt water comprise another natural environment to which materiel may be exposed. This environment generates problems similar to the tropical environment, less the fungous problem. The principal effect is severe corrosion. Typical failures are loss of mechanical strength, alteration of electrical properties, and interference with functional performance.

3-4.3.2 Induced Environments

Extreme induced environments that may affect materiel derive from transportation, handling, storage, and the operational environment, which may include combat. Transportation and handling cause materiel to be subjected to shock and vibration. Normally, the effects of excessive shock are obvious visually in all assemblies except those that consist of or incorporate ordnance devices, or when materials have been stressed beyond yield points, but are not broken. Typical effects are broken wires and solder joints, dislocated components, bent or broken brackets and supports, cracked materials, and physically deformed components. Typical effects on ordnance items are deformation, separation, and cracking of the propellant grain or charge. Excessive vibration can result in similar damage, and in addition can cause material fatigue. Items in storage, particularly in unprotected storage, are subject to failure modes identical to those described for natural environments, and also may fail due to aging.

The use of materiel in combat can result in its exposure to all of the foregoing environments, and to hostile action. Previously described effects will be aggravated, because maintenance, particularly preventive maintenance, is apt to be neglected. Combat also can generate some unique problems since chemical agents and nuclear radiation may be encountered. Chemical aerosols in sufficient concentrations could cause corrosion, and extreme nuclear radiation could render electronic materiel inoperative and make mechanical materiel radioactive. In general, materiel will survive in any chemical or radioactive environment in which personnel can survive. In such circumstances, materiel decontamination and personnel protection must be considered in addition to normal maintenance.

Electronic components, because of their physical structure and the manner in which they are assembled, will fail structurally more quickly than mechanical components when exposed to equally severe transportation and handling environments. Electronic components also are sensitive to natural environments. Failures in typical components that may result when they are exposed to several environmental parameters are shown in Table **3-4.**

3-4.3.3 Maintenance Engineering Actions

Design engineering, which has the final responsibility for materiel design, is knowledgeable of extreme environments more from an academic and test laboratory point of view than from field experience. On the other hand, maintenance engineering should have first-hand experience with field environments, the maintenance problems that are generated, and with concepts and designs that have worked and those that have not. The most important steps that maintenance engineering can take to influence design properly are first to insure that proper concepts are selected (full tracks, half tracks, or wheels, for example), and then to impart.all relevant field experience and recommendations to design engineering before design is initiated.

TABLE 3-4. EFFECTS OF ENVIRONMENTAL PARAMETERS ON ELECTRONIC COMPONENTS

Components	Vibration	Shock	Temperature	Humidity	Salt Spray	Storage
Capacitors						
Ceramic	Increased lead breakage; piezoelectric effect; body and seal breakage	Lead breakage; piezoelectric effect; body and seal breakage	Changes in dielectric constant and capacitance; lowered insulation resistance with high temperature	----	Corrosion; shorts	Decreased capacitance; silver-ion migration
Tantalum	Opens; shorts; current surges; lead breakage	Opens; lead breakage	Electrolyte leakage; change in capacitance; insulation resistance; series resistance	Decreased insulation resistance; increased dielectric breakdown; increase in shorts	Corrosion	Electrolyte leakage. decreased insulation resistance; increase in shorts
Crystals	Opens	Opens	Drift; microphonics	Drift	----	Drift
Resistors	Lead breakage; cracking	Cracking; opens	Change in resistance; opens; shorts	Change in resistance; shorts; opens	Change in resistance; lead corrosion	Change in resistance
Semiconductors:						
Diodes	Opens	opens	Change in voltage breakdown; increased current leakage; increase in opens and shorts	Increased current leakage	Corrosion of lead and case	Increased current leakage
Integrated circuits and hybrid devices	Shorts; intermittents	Shorts; opens	Opens	Opens; performance degradation	Corrosion; opens	Shorts; opens. performance degradation
Transistors	Opens; functional disintegration	Opens; seal breakage	Increased leakage current; changes in gain; increases in opens and shorts	Increased leakage current; decreased current gain. If sealed, no effect	Increased leakage current; decreased current gain. If sealed, no effect	Seal leakage; changes in parameters
Thermistors	Lead breakage; case cracking; open circuit	Lead breakage; case cracking; open circuit	Increased shorts and opens	Change in resistance	Lead corrosion; change in resistance	Change in resistance
Tubes. electron	Opens; shorts; microphonics; loosening of elements; changes in Characteristics	Opens; shorts; changes in characteristics	Shorts; temporary change in characteristics; formation of leakage paths; increased contact potential; shortening of heater life; gassiness; bulb puncture	Change in characteristics; leakage path; arcing	Shorts; corrosion; leakage path; arcing	Change in characteristics; leaks; gassiness

As design progresses, maintenance engineering reviews specifications, drawings, hardware, and test data to insure that environmental factors are receiving proper consideration. If the materiel is to be deployed worldwide, the ability of the materiel to withstand the full gamut of natural and induced environments is evaluated. Proper materials, finishes, shock mounting, and containers can eliminate or reduce potential corrosion, shock, vibration, fungous, temperature, and humidity problems. Proper mechanical design will assist with ice, snow, and sand problems. Equally important, the ability of personnel to use the proposed support equipment and to perform effective maintenance is evaluated. Shelters are a prime requirement in extreme environments, and support materiel also must be environmentally rugged.

3-4.4 LIFE CYCLE MAINTENANCE

Design is a source of maintenance requirements, and maintenance requirements are the source of support requirements and costs. Design is also a source of materiel acquisition costs. The maintenance engineering responsibility to establish design requirements that will result in lowest materiel life cycle costs (acquisition plus life cycle support) is accomplished by trading off design alternatives that eliminate or reduce maintenance requirements and establishing the indicated design requirements. The trade-offs are conducted throughout the materiel life cycle, but are most prevalent during the conceptual, validation, and early full-scale development phases.

There are various design approaches that will result in elimination or reduction of maintenance requirements. These cover a broad spectrum, ranging from the extreme of no maintenance through designs that require varying degrees of maintenance. No maintenance is a quantitative term, which means that no maintenance will ever be performed at any maintenance level throughout the materiel life cycle. Reduced maintenance is a qualitative term that is meaningful only when a comparison is made between two design approaches. If one acknowledges the fact that even the simple act of replacing a flashlight battery is maintenance, it is unreasonable to anticipate the complete elimination of any appreciable portion of the maintenance requirements for complex materiel. On the other hand, there are many ways to reduce these requirements.

A design feature that incorporates no maintenance always has a favorable impact on support requirements and, if it does not increase acquisition costs when compared to any other design approach, is an instant winner. If the feature does increase acquisition costs, a decision must be preceded by calculations of support costs for alternate approaches that do require maintenance. If both acquisition and support costs, or the differences between them, are relatively insignificant, the no-maintenance approach should be selected even if it appears to cost more. Life cycle costing is not an exact science, whereas the positive effects of no maintenance are self-evident. If there is any reasonable chance that a no-maintenance design will evolve into one that requires maintenance, it should be avoided. The support impact of having to perform unplanned maintenance on deployed materiel is self-evident.

Three basic ways to reduce maintenance are to extend the time between maintenance actions, reduce the time to perform maintenance actions, and discard rather than repair failed subassemblies or assemblies. The time between maintenance periods can be extended by increasing reliability in the case of materiel subject to random failures, or by selecting improved components in the case of items subject to wearout. An example of the former is an electronic component, and of the latter, a sealed bearing that will require servicing or replacement one or more times during the life of the materiel. Normally, an increase in reliability will adversely and sometimes significantly impact acquisition costs, and will favorably impact all support resource requirements, except in some cases, a reduced number of highly reliable repair parts may cost more than a greater number of less reliable parts, The extension of time between servicing or replacement of items is of particular importance when large quantities of materiel are deployed.

Once operational availability requirements have been satisfied, there is little opportunity to reduce support costs at the organizational level by reducing the time required to perform corrective maintenance. In this case, all necessary support resources are in place to correct random failures, and large differences between average maintenance times such as 1 hour versus 2 hours normally will not permit a reduction in organizational support assets. The opposite is true for scheduled organizational maintenance and all maintenance performed by higher maintenance levels. All of this maintenance is scheduled, and an appreciable reduction in maintenance times normally will permit a reduction in all support resources except repair parts.

Possibly the most common way to reduce maintenance requirements for electronic materiel is to replace and discard failed modules. The support advantages of such an approach are numerous. The only requirements at the organizational level are personnel, minimum publications, simple tools, a fault isolation system, and repair parts. At higher levels, nothing is required except repair parts, supply management, transportation, and support for the organizational support equipment. Normally, materiel acquisition costs and repair parts costs for this approach will increase, and the costs for all other support resources will decrease.

Sometimes it is feasible to delay discard-at-failure versus maintenance decisions until some field failure data are available. Such an approach is recommended as a last resort, since a discard-at-failure decision early in the development phase is necessary to permit acceptance of favorable materiel design features that normally cannot be incorporated otherwise. However, if a discard-at-failure decision cannot be made during early development, the deferred decision approach should be considered when:

a. Materiel mission effectiveness will not be adversely affected.

b. There is a high probability that usage data will support a discard-at-failure concept.

c. The cost avoidance potential is significant.

As an example of when a deferred decision is feasible, consider a high-density, helicopter-launched missile that either must be discarded at failure or repaired at a depot. Regardless of the maintenance concept, the missile will be subjected to a go/no-go test before being loaded on a helicopter. The predicted reliability for the missile is quite high, and studies show that, during the planned life cycle of the missile, it is significantly more economical to discard the few failed missiles anticipated than to establish a depot repair capability through the procurement of tools, test equipment, repair parts, technical documentation, etc. On the other hand, if the predicted reliability is not attained, cost-effectiveness considerations dictate depot maintenance. In such a situation, a decision can be deferred by deploying the missile for a period of time (a year or more depending upon the length of the production program) and storing all units that fail. At the end of this time, if the predicted reliability is achieved, a firm discard-at-failure policy is established and the stored, failed missiles are salvaged. If the high reliability is not achieved, a depot maintenance capability is planned and implemented. Interim factory maintenance is provided, if necessary.

It is possible safely to defer a maintenance decision in the assumed example because the program involves a large number of missiles with an expected high degree of reliability. Even if the predicted reliability is not attained, it is reasonable to believe that the reliability realized will not fall so far short of the predicted reliability that operational requirements cannot be met with the large stockpile of missiles that exists. This approach cannot be used safely with a low-density system. In such a case, there is no stockpile of items from which to draw while usage data are being acquired. A significant number of unrepaired failures will place the system in a nonoperationally ready status, and it will remain in this status until a maintenance and supply capability is established.

3-4.5 PERSONNEL TRAINING REQUIREMENTS

Deployed materiel normally generates requirements for personnel to operate and maintain it. Operators, by definition, exist only at the organizational level. Depending upon the maintenance concept, maintenance personnel may exist at any of the maintenance levels. The required skill levels for operators and maintenance personnel depend upon the complexity of the functions they must perform. Functional complexity depends upon materiel design. Maintenance engineering evaluates design for its impact on skill level requirements, and requests appropriate changes.

Many benefits accrue when qualitative personnel requirements are reduced. Personnel are in short supply, and the number capable of being trained for high skill tasks comprises only a small percentage of the total. This means that it is not feasible to deploy materiel that requires undue quantities of highly skilled personnel. Training requires the diversion of potential operators and maintenance personnel to the instructor role, takes time, consumes resources, and the higher the required skill level, the more comprehensive the training must be. Finally, during the materiel life cycle, personnel costs comprise the largest single element of operating and maintenance costs, and the higher the skill level, the greater the costs will be.

Required skill levels are directly proportional to the complexity of personnel functions that must be performed, and are frequently inversely proportional to materiel complexity. Consider operators for an antiballistic missile weapon system and a tactical missile weapon system. Once a decision is made to initiate an antiballistic missile mission, subsequent required operator functions are beyond human capabilities. Consequently, most operator tasks are eliminated by the use of a computer and automatic circuit switching. If some malfunction does occur, about the only thing an operator can do is to observe an indicator light and initiate a new automatic sequence of events.

Contrast the foregoing with the role of the tactical missile system operator. Here, the operator participates in calculating firing data, observing countdown progress, and, in the event of difficulties, applying judgment and experience to the solution of problems. This operator can affect the success of a mission to the degree that he can cause an unsuccessful mission when all materiel is operating perfectly. This example cannot be concluded with the statement that the antiballistic missile system operator is of a lower skill level or requires less training than the other operator, because responsibility enters the picture. However, it does demonstrate the fact that complex materiel need not result in complex operator tasks.

Operator tasks are eliminated when dictated by mission requirements, or when a life cycle cost savings can be demonstrated by requiring materiel automatically to accomplish functions that can be performed by personnel. The complexity of the remaining tasks is reduced by applying good human factors principles. Maintenance engineering should work closely with training and human factors personnel to insure that an optimum balance exists between materiel and personnel functional requirements, and that those functions assigned to personnel are not unduly complex.

Maintenance tasks are eliminated at some maintenance levels for the same reasons and in the same way as operator tasks. However, unlike operator tasks, maintenance tasks eliminated at the organizational level frequently remain to be accomplished elsewhere. Electronic end items such as communication sets, radars, computers, missiles, and gun laying equipment are a part of many types of Army materiel. These items are becoming so complex that manual troubleshooting is not feasible. Consequently, some type of automatic fault isolation to an assembly or subassembly is accomplished, and the defective item is removed and replaced. Note, however, that unless the removed item is discarded, the fault isolation functions eliminated at the organizational level must be performed at some other maintenance level. Note also that even with a highly reliable and completely automatic fault isolation capability and a policy to discard all failed items, highly skilled maintenance personnel must be retained somewhere in the support subsystem to repair materiel when the fault isolation equipment fails. In short, the elimination of electronic maintenance functions at the organizational level normally will result in increased maintenance skill requirements at some other maintenance level, but quantitative requirements will be reduced.

The complexity of maintenance tasks can be reduced by the application of good maintainability principles. The complexity of electronic maintenance usually results from fault isolation requirements, accessibility, and packaging. On the other hand, mechanical and hydraulic maintenance complexity derives in large part only from accessibility and packaging. The use of automatic fault isolation was discussed as a means of eliminating electronic maintenance functions. This same technique, coupled with good accessibility and packaging, simplifies electronic maintenance at all maintenance levels. Good accessibility and packaging alone will do the same for mechanical and hydraulic maintenance.

This discussion has concerned itself with materiel systems. Maintenance requirements for some components, subassemblies, etc., can be eliminated by substituting items which will not fail and which require no servicing. Generally, this will not result in a reduction of maintenance skill and training requirements because skilled personnel are required to maintain the remainder of the system. It does impact maintenance time requirements and perhaps quantitative personnel requirements.

3-4.6 SAFETY

Materiel is safe when it is free from those hazards that can cause injury or death to personnel and damage or loss of equipment and property. Equipment incorporating the ultimate in safety would pose no hazard to personnel and would not be subject to any hazard as a result of operation and maintenance. Even the best design principles and test procedures cannot eliminate all hazards. Inasmuch as hazards cannot be completely designed out of systems, it is imperative that those that remain be recognized and measures taken to minimize their danger.

The broad concept of safety begins with basic materiel research in the laboratory, and is emphasized particularly during the research and development phase. The safety of materiel is proven by specialized development and functional and engineering testing. During manufacture of the end products and in packaging and delivery to the user, safety consciousness is never forgotten. Consideration in the early stages of design reduces the number of modifications required to correct deficiencies, facilitates production, improves operational effectiveness, and assures materiel safety to the user. The safety of materiel, therefore, must first be initiated in a well-conceived design and must be followed throughout the detailed design stages to assure that the safety of the system is "designed in".

Safety precautions designed into equipment are necessary usually as safeguards to lapses of attention. If a mechanic must divert attention from his task to be intent on observing safety precautions, the remainder of his attention may be inadequate for doing his job well; it will certainly take him longer to do the job. Safety measures, therefore, should take into account behavior liabilities such as those mentioned.

The design of any equipment must embody features for the protection of personnel and materiel from electrical and mechanical hazards and, also, from those dangers that might arise from fire, elevated operating temperatures, toxic fumes, etc. There are various methods for incorporating adequate safeguards, many of which are implicit in routine design procedures. Certain procedures, design practices, and related information are of such importance as to warrant special attention. Mission effectiveness suffers when personnel are injured or materiel is damaged.

Maintenance work, so vital to the successful operation of any item of equipment, is of greater import when military materiel is involved. During routine scheduled and special maintenance, the "designed in" safety of the system must not be jeopardized. Each operation must be questioned for the possibility that the work, the change, the redesign, and/or the work order, when accomplished, will in any way reflect adversely on the capability, reliability, and safety of the system. In addition, continued hazard evaluation, based on engineering data and scientific observation, together with actions designed to minimize control or protect against these hazards, is necessary. Maintenance work, therefore, must be considered in the light of maintaining the integrity of weapon and end product safety.

Some potential safety hazards that maintenance engineering should eliminate or control to insure adequate protection to personnel and materiel are toxic gas sources, electrical shock, fire and radiation sources, high noise levels, moving mechanical assemblies, and protruding structural members. For example, fuels, engine exhausts, and hydraulic fluids generate fumes that are toxic in varying concentrations, and can be encountered during operation and maintenance of several types of Army materiel. Maintenance engineering insures that materiel design, transportation, handling and storage plans, maintenance facilities, support equipment, and technical publications preclude any exposure of personnel to dangerous concentrations of these and other toxic fumes.

3-4.6.1 Safety Considerations of the Electrical System

Electrical and electronic materiel must be designed to eliminate or minimize the possibility that operators and maintenance personnel will be injured or will damage materiel accidentally while performing their functions. The materiel also must be designed to protect itself from.further damage when a component malfunctions. Several potential sources of serious personnel injuries are electrical shock and burns, radiation, implosions, explosions, rotating or oscillating components, and protruding structural members. The major sources of materiel damage are failed components, such as insulating materials, that result in excessive heat-ing, including fires, and component overloads that stress the components beyond the point of failure.

3-4.6.1.I Electricul Shock (Ref. I)

The principal contingency to guard against is shock. Even a small shock is dangerous. Burns or nervous system injuries are not the only possible effects; equipment damage and additional physical harm to personnel can result from the involuntary reactions that accompany electrical shock.

Potentials exceeding 50 V rms are possible electrical shock. hazards. Research reveals that most deaths result from contact with the relatively low potentials, ranging from 70 to 500 V, although, under extraordinary circumstances, even lower potentials can cause injury. Many severe injuries are not directly caused by electrical shock, however, but by reflex action and the consequent impact of the body with nearby objects.

The effect of electrical shock depends upon the resistance of the body, the current path through the body, the duration of the shock, the amount of current and voltage, the frequency of the current, and the physical condition of the individual. The duration times of short electrical shocks that possibly could cause heart attack are listed in Table 3-5.

The danger to personnel from electrical shock should be avoided by suitable interlocks, grounding means, enclosures, or other protective devices. Some contact with electrical potentials can be expected wherever maintenance personnel, by the very nature of their duties, are exposed to live terminals. Both shocks and burns, however, can be minimized by greater care in design, and by a better understanding of electrical characteristics.

3-4.6.I.2 Prevention of Electricul Shock (Ref. I)

There are several methods of attaining adequate personnel protection, such as enclosing the components and providing access-door safety switches operated either by door pressure or by a locking mechanism, automatic operation of the main equipment switch when the door is opened, and automatic grounding of components when the unit is opened for access to the components. The primary methods of electrical shock prevention are described in the following paragraphs.

TABLE 3-5. POSSIBLE HEART ATTACK FROM SHORT ELECTRICAL SHOCKS

Duration, sec	Direct Current, mA	Alternating Current, mA	
		60 Hz	10,000 Hz
0.03	1300	1000	1100
3.00	500	100	500

a. Safety Markings. Markings should be provided to warn personnel of hazardous conditions and to highlight the precautions that must be observed to insure safety of personnel and equipment.

Warning signs marked **CAUTION—HIGH VOLTAGE** or **CAUTION _______ VOLTS** should be placed in prominent positions on safety covers and access doors, and inside equipment wherever danger might be encountered. These signs should be durable, easily read, and placed so that dust or other foreign matter will not, in time, obscure the warnings. Because signs are not physical barriers, they should be relied on only if no other method of protection is feasible. Electrical equipment should be marked, as required, in accordance with the National Electric Code.

b. Safety Color. The predominant color of equipment designed for safety, protective, or emergency purposes should be in accordance with Federal standards.

c. Safety Warming Devices. Suitable bells, horns, vibration devices, lights, or other signals should be provided and located where they may be easily and obviously sensed by personnel required to take corrective action. Multiple safety installations should be installed when required.

d. Safety Switches. Three types of safety switches that can be used to prevent electrical shock are interlocks, battleshort switches, and main power switches. Each type is described separately in the following paragraphs:

(1) *Interlocks.* A switch that automatically opens the power circuit when an access door, cover, or lid of a piece of equipment is opened is a simple safeguard. When the equipment must be worked on with the power on, interlocks must be provided with some means for closing the circuit when the door is opened. In this case, visible means must be provided to show that danger exists.

Interlock switches are used to remove power during maintenance operations. Each cover and door providing access to potentials greater than 40 V should be equipped with interlocks. Interlock systems should also be provided to ground capacitors having a discharge time greater than 5 sec when the enclosure is opened.

An interlock switch ordinarily is wired in series with one of the primary service leads to the power supply unit. It is usually actuated by a removable access cover, thus breaking the circuit when the enclosure is entered. When more than' one interlock switch is used, the switches are wired in series. Thus, one switch might be installed on the access door of an operating subassembly and another on the dust cover of the power supply.

Because electronic equipment often must be serviced with the power on, a switch enabling maintenance personnel to bypass the interlock system should be mounted inside the equipment. The switch should be located so that reclosing of the access door or cover automatically restores interlock protection. Also, a panel-mounted visual indicator such as a neon lamp should be provided, as well as a suitable nameplate to warn personnel when interlock protection is removed.

(2) *Battle-short Switch.* A battle-short switch, or terminals for connection of an external switch, should be provided to render all interlocks inoperative. The panel-mounted or remotely controlled battle-short switch is designated for emergency use only. The circuit consists of a single switch, wired in parallel with the interlock system. Closing the battle-short switch places a short circuit across all interlock switches, thus assuring incoming power regardless of accidental opening of the interlock switches.

(3) *Main Power Switch.* Each equipment should be furnished with a clearly labeled main power switch that will remove all power from the equipment by opening all leads from the main power service connections. Main power switches equipped with adequate safeguards protect against possible heavy arcing. Safeguards such as barriers, which shield fuses and conducting metal parts, and protective devices, which prevent opening the switch box with the switch closed, should be provided as protection for personnel. Switches incorporating such safeguards are standardized, commercially obtainable equipment.

e. Discharging Devices. Discharging devices to discharge high-voltage circuits (including contactable surfaces of cathode-ray tubes) and capacitors should be provided unless the devices discharge to 30 V within 2 sec or less. These protective devices should be positive acting and highly reliable, and should actuate automatically when the case or rack is opened. The use of shorting mechanisms or bleeder resistances actuated either by mechanical release or by an electrical solenoid when the door or cover is open should be considered.

f. Grounding. Various grounding techniques are used to protect personnel from dangerous voltages in equipment. All enclosures, exposed parts, and chassis should be maintained at ground potential, using the *same* common ground.

Specifications for the reduction of electrical noise interference should be consulted to determine the maximum permissible resistance of a grounding system. Reliable grounding systems should be incorporated in all electronic equipment. Enclosures and chassis should not be used as electric conductors to complete a circuit because of possible intercircuit interference.

g. Powerlines. Safety considerations should not be confined to high-voltage apparatus. It is important that attention be given to the hazards of powerlines. Severe shocks and serious burns are known to result from personnel contacting, short-circuiting, or grounding the incoming lines. Both sides of the powerlines and all branches should be fused to prevent a main powerline malfunction caused by a transformer or motor failure that would result in grounding of the primary supply line.

3-4.6.1.3 *Radiation Hazards*

Electrical and electronic materiel may produce electromagnetic radiation that is hazardous to personnel and to other materiel. This energy may be radiated as the output of an end item, such as radiation from a radar, or may be associated with components or assemblies within the materiel.

Personnel exposure to more than 10 mW per cm^2 of microwave radiation energy should be prevented. Attenuation devices should be used to control radiation from components and assemblies to this level. Hazardous exposure to radiation from radars is prevented by strict adherence to proper operating and maintenance procedures.

Certain devices, such as traveling-wave tubes, use intense magnetic fields that may be hazardous to personnel. Such devices whose fields exceed 1000 gauss should be equipped with interlock switches to protect maintenance personnel. When fields exceed 1000 gauss and a personnel exposure potential exists, all removable protective devices should be placarded with warnings that identify a magnetic field hazard and specify an allowable exposure period. Exposure in fields up to 5000 gauss is limited to 3 days per man-year, and between 5000 and 15,000 gauss, to 15 min per man-year.

The exposure of materiel to radiofrequency energy can result in damage to or destruction of components and subsystems, or merely result in degraded operation. Missiles shipped with installed electroexplosive devices pose a particular problem since the devices are susceptible to radiation initiation. In some design applications, initiation of the device may result in propellant ignition or detonation of explosives, and in others, in activation of a battery or similar device.. The end result is at worst an explosion, and at best a maintenance task. A basic way to protect materiel from radiofrequency energy is by shielding.

3-4.6.1.4 *Implosion and Explosion* (Ref. 1)

Equipment that may be operated, maintained, or stored in an explosive atmosphere should be designed so as to eliminate the possibility of an explosion. All electrical equipment that will be used in the vicinity of flammable gases or vapors should be explosion-proof, Danger to personnel from an explosion should be avoided by separation of hazardous substances from heat sources and by incorporation of spark arrestors, suitable vents and drains, and other fire prevention measures.

The cathode-ray tube is a special hazard, in that physical damage can result from implosion. If the tube is accidentally nicked or scratched, resultant implosion might not occur until days later. The tube face, therefore, should be shielded by a shatterproof glass attached to the panel. Signs warning personnel that the neck of the tube is easily broken and must be handled with caution should be posted inside the equipment.

The terminal end of cathode-ray tubes should be located within the equipment housing whenever possible. If the terminal end does extend outside the equipment housing, a strong cover for the tube should be provided. The cover should be anchored firmly to the main structure of the housing to withstand shipping damage and rough handling and to prevent external pressures from being exerted on the wires and terminal end of the tube.

3-4.6.1.5 *Mechanical Hazards (Ref. 1)*

Shields and guards should be made part of the materiel to prevent personnel from accidentally contacting rotating or oscillating parts such as gears, couplings, levers, cams, latches, or heavy solenoid equipment. Moving parts should be enclosed or shielded by guards. When such protection is not possible, adequate warning signs should be provided. High-temperature parts should be guarded or located so that contact will not occur during normal operation. Guards should not prevent the inspection of mechanisms, the failure of which will cause a hazardous condition. Guards also should be designed to permit inspection without removal whenever possible.

When access to rotating or oscillating parts is required for maintenance, it might be desirable to equip the protective covers or housings with safety switches or interlocks. The cover or housing should bear a warning sign worded:

CAUTION
KEEP CLEAR OF ROTATING PARTS

Ventilation should be provided so that no part or material attains a temperature that will tend to damage or appreciably reduce its normal useful life. No exposed parts of the equipment should, under any condition of operation, attain temperatures hazardous to personnel. Forced air may be used for cooling if replaceable, renewable, or cleanable dust filters are installed. Air exhaust openings should not be located on front panels or other locations that expose personnel to direct drafts.

Some housings, cabinets, and covers require the use of perforations to provide air circulation. The size of the perforations should be limited to 0.5 in. High-voltage, rotating, or oscillating components within should be set back from the perforated surface far enough to prevent accidental contact by personnel. If this cannot be done, the size of the perforations should be reduced.

Electronic chassis in their normal installed positions should be securely enclosed. Stops should be provided on chassis slides to prevent the chassis from being pulled out too far and dropped. Suitable handles or similar provisions should be furnished for removing chassis from enclosures. Bails or other suitable means should be provided to protect parts when the chassis is removed and inverted for maintenance, and to protect the hands as the chassis is placed on the bench.

Projecting edges, protrusions, rails, or corners on which personnel might injure themselves should be avoided. When such protrusions are unavoidable, bumper guards and covers should be provided. These should be of materials that are not susceptible to climatic damage, and should be firmly attached to last the lifetime of the equipment.

3-4.6.1.6 *Overload Protection (Ref. 1)*

Protective devices should be provided within equipment for primary circuits and other circuits, as required, for protection from damage due to overload and excessive heating. Any part likely to carry an overload due to malfunction of circuits, poor adjustments, antenna or tube casualty, or other deleterious effects should be designed to care for such an overload. When this is impractical, circuit breakers, relays, fuses, or other devices should be included to protect the affected parts.

Additional design considerations are as follows:

a. Fuses (or circuit breakers) should be provided so that each unit of a system is separately fused and adequately protected from harmful powerline variations or transient voltages.

b. Fuses should be located on the front panel of the unit where they can be seen and replaced without removing other parts. Fuses should not be located inside the equipment.

c. Fuses should be grouped in a minimum number of central, readily accessible locations and should be replaceable by the equipment operator whenever possible without the use of tools.

d. Spare fuses should be provided and located near the fuseholder, and labels adjacent to the fuseholder should provide both fuse value and function. (If space is limited, the fuse value rather than the function should be indicated.)

e. Fuseholder cups or caps should be of quick-disconnect rather than screw-in type, and should be knurled and large enough to be easily removed by hand.

f. Fuse installations should be designed so that only the "cold" terminal of the fuse can be touched by personnel.

g. When circuit breakers are used, the design should be such that the restoring or switching device is readily accessible to the operator. **A** circuit breaker that gives a visual indication when the breaker is tripped and will trip even if the switch lever is held in position should be selected. Overload or other protective devices that do not alter the normal performance characteristics of the source or load should be provided. The use of protective devices in secondary circuits should be held to a minimum.

Overloads normally result from failed components or insulation failures, both of which can cause additional failures in the same equipment. Other types of damaging overloads can result from improper maintenance actions such as application of excessive or reversed polarity test loads, or improper handling of components. Solid-state parts and circuits particularly are susceptible to high voltages and high operating temperatures. Materiel is protected against maintenance damage by design features, but design protection must be supplemented with disciplined adherence to proper procedures. For example, materiel can be provided with buffered test points that keep components from being shorted during tests; keyed test point connectors to insure proper test polarities; and thermal switches to preclude overheating during bench testing. The test equipment can be designed with fail-safe features so that it cannot introduce abnormal stresses. However, selection of test equipment settings is controlled by procedures. Component handling is governed totally by procedures. For example, metal oxide semiconductor devices are highly susceptible to static electricity. Comprehensive procedures exist to govern their packaging, shipment, receiving, inspection, storage, and handling. If these procedures are not observed, the devices probably will be damaged.

3-4.6.1.7 *Insulation Materials*

Electrical insulation materials used in electrical and electronic materiel affect both its safety and service life. Serious damage, including fires, can result from electrical shorts. Lesser degrees of current leakage can result in intermittent materiel operation and a prohibitive length of time spent in fault isolation. Maintenance engineering should insure that selected insulation materials will provide maximum service life commensurate with cost and safety considerations.

Selection of the proper type of insulation depends upon the natural and induced environments to which the materiel will be exposed during its life cycle. There are some universally desirable insulation features and some unique to the proposed application. Desirable features independent of application include resistance to aging, flame, fungus, and moisture. Desirable features dependent upon application include resistance to oil, gasoline, weathering, ozone, sunlight, temperature, abrasion, and radiation.

Numerous organic and inorganic types of insulation material are available, but no single type can be rated excellent with regard to its ability to resist all environmental parameters. Consequently, insulation selection is a complex discipline, and maintenance engineering monitors the selection process. The monitoring is best accomplished by listing the natural and induced environments for the application in question, determining proposed types of insulation, and evaluating the proposed types by using insulation specifications or an authoritative design handbook (see Ref. 19).

3-4.6.1.8 *Fire* (Ref. 1)

All reasonable precautions should be taken to minimize fire hazards. In particular, any capacitors, inductors, or motors that are possible fire hazards should be enclosed by a noncombustible material having minimum openings. Because many equipments are installed in confined spaces, materials that can produce toxic fumes should not be used. Finished materiel should be checked carefully for verification of protective features in the design. Materials that, under adverse operating conditions, will liberate gases or liquids that are or may combine with the atmosphere to become combustible mixtures must be avoided. Equipment must be designed so that flammable vapors will not be emitted during storage or operation. Suitable warnings or automatic cutoffs should be provided in case such vapors are emitted during operation. Equipment should not produce undesirable or dangerous smoke and fumes.

When known fire hazards exist, or may be created by the equipment itself, hand-operated, portable fire extinguishers must be provided. The extinguishers must be located so that they are easily and immediately accessible, and they must be the type suitable for the type of fire most likely to occur in the area. The three general classes of fires are as follows:

Class A. Fires occurring in ordinary combustible materials—such as wood, paper, and rags—which can be quenched with water or solutions containing water.

Class B. Fires occurring in flammable liquids—such as gasoline and other fuels, solvents, greases, and similar substances—which can be smothered by diluting, eliminating air, or blanketing.

Class C. Fires occurring in electrical equipment—such as motors, transformers, and switches—which must be extinguished by a non-conductor of electricity.

The classes of fires on which an extinguisher may be safely and efficiently used are clearly noted on the extinguisher. Some extinguishers are approved for multiple classes of fires such as A-B-C and B-C. Others may have a single classification such as **A.** An extinguisher must not be used on a type of fire for which it is not approved, and water must not be used on Class B and C fires.

3-4.7 CONSTRUCTION TECHNIQUES

The construction techniques that are applied to materiel have a significant influence on its life cycle maintenance requirements and maintainability characteristics. Poor techniques will always result in either more frequent maintenance or more time-consuming maintenance, and may result in both. Some construction features of particular interest to maintenance engineering include material selection, component protection, test points, provisions for indirect testing, bearing selection, lubrication requirements, fixed joints, and self-adjusting components.

3-4.7.1 Material Selection

The materials from which materiel is fabricated are selected on the basis of many considerations. Some of the most important of these are weight, strength, cost, adaptability to required manufacturing processes, compatibility with the operational environment, fire resistance, and ease of repair. These considerations are applicable in varying degrees to all types of materiel. The first four fall completely within the purview of design and production engineering. Maintenance engineering has a monitoring responsibility with regard to the others.

The selected materials should be compatible with the operational environment. Materials should be selected on the basis of their ability to resist fungus, corrosion, and any compounds such as gasoline and oil likely to be encountered because of their application. The ability to retain the physical properties of flexibility, strength, and resilience in extreme temperatures is important. The materials selected for external surfaces must be capable of being easily cleaned. In this respect, it should be noted that helicopters, tanks, trucks, guns, shop vans, etc., are cleaned with steam, water, and chemical compounds.

The requirement for fire-resistant materials in Army materiel is universal and self-evident. Every item of materiel should be as impervious to fire as the state of the art and economy will permit. There is a constant fire potential during operation of virtually any type of materiel, and there is always a fire potential when materiel is exposed to enemy action. Materials that produce toxic fumes when burning or overheated should be avoided, and those exposed to rocket plumes, engine heat, etc., should be fireproof.

The ease with which materials can be repaired is a very important consideration that is easily overlooked. Among other considerations, ease of repair is a function of required equipment and skills. When feasible, materials should be selected that can be repaired with equipment and skills available at the organizational level. For example, structural members that can be fusion welded with an oxygen acetylene torch probably can be repaired by organizational maintenance. If electron-beam welding is required, the maintenance probably would be accomplished at a depot. Material repairs that require curing or baking in controlled temperatures comprise another category of maintenance that is beyond the capability of the organizational level.

3-4.7.2 Physical Protection for Components

Several construction techniques can be used to provide physical protection for electrical and electronic components. Among the most widely used are conformal coating, potting, and structural design that controls vibration.

3-4.7.2.1 Conformal Coating (Ref. 5)

A discussion of the use, composition, application, maintenance aspects, and safety considerations of conformal coatings follows:

a. Usage. Conformal coatings, which are liquid organic film-forming materials, are applied to electronic components and assemblies to provide environmental protection. The material is applied in a continuous layer to conform to the shape of the component or assembly. The coating protects components from fungus, dirt, moisture, salt air, fingerprints, etc., and from vibration and shock. The normal type of electronic assemblies protected by conformal coatings are printed wiring boards.

b. Material Types and Application. Many different liquid organic film-forming materials are used as conformal coatings. The coatings vary from simple solutions of organic resins that "set" by evaporation of the solvent carrier, to chemical curing of two-component materials that must be carefully mixed and cured at room or elevated temperature. Epoxy, polyurethane, and silicone coating materials are widely used for military applications. The epoxy resin coating materials are only available as two-component, chemically curing systems. The polyurethane resin coating materials are available as two-component, chemically curing systems and as one-component systems that cure by reacting with either oxygen or moisture in the surrounding air. The silicone rubber coating materials are available as two-component, chemically curing systems, and as one-component, chemically blocked systems that cure by exposure to moisture in the air.

The surface of a printed wiring board must be cleaned of contaminants such as dust, dirt, fingerprints, body oils, and solder flux before the conformal coating is applied. Contaminants must be removed so that the conformal coating will adhere to the board surface and to prevent trapping of contamination underneath the conformal coating. Improperly cleaned boards will present coating problems and have markedly reduced insulating qualities, especially at elevated temperatures or when exposed to humidity. All organic conformal coating materials have reduced insulation resistance properties at elevated temperatures and in high-humidity environments. A combined elevated temperature and high-humidity environment will cause the greatest insulation resistance decrease. Silicone rubber conformal coating materials have the best high-temperature insulation resistance properties.

Primers are required generally to provide adhesion of silicone coatings and are required occasionally for polyurethane coatings. Epoxy coatings do not require primers. A thin, 0.001 to 0.003 in. thick conformal coating applied to a properly cleaned assembly will provide adequate protection from environmental contamination (dirt, dust, humidity, salt spray, etc.) and will provide flashover protection at high altitudes (low pressures). Heavier coatings may be required to provide mechanical support for components not mounted flush to the board surface. The conformal coating must bridge the gap between the component body and the board surface, and must attach the component to the board so that relative movement cannot occur between the component and the board. Components not attached to the board surface can experience sufficient movement to cause lead fatigue and component failure during exposure to vibration and shock environments. Conformal coatings should not be depended upon to support the heavier or larger components. Such components, especially large capacitors that have relatively large bodies and small-diameter leads, should be filleted or bonded to the board surface for adequate support.

c. Maintenance Considerations. From a maintenance point of view, conformal coatings are ideal for components and assemblies that are to be discarded at failure. The repair of coated items necessitates removal of the coating by chemical or mechanical means, and replacement of the coating after repair.

d. Safety Considerations. A cancer-suspect chemical with the chemical name 4,4′-methylene(bis)-2-chloroaniline (common name MOCA) is used widely in the preparation of conformal coatings. Products containing such cancer-suspect chemicals, or carcinogens, must be handled in accordance with Public Law 91-596, the Occupational Safety and Health Act of 1970. It virtually would be impossible for field troops to comply with the public law. In most cases, alternate materials are available which may be substituted for MOCA. Maintenance engineering should insure that conformal coating specifications preclude the use of MOCA.

3-4.7.2.2 *Potting* (Ref. *5*)

A discussion of the use, composition, application, maintenance aspects, and safety considerations of potting compounds follows:

a. Usage. Potting is the embedment of a component or an assembly of components in a permanent container (pot), using a liquid resin that is subsequently cured into a solid. Potting provides component and assembly protection similar to that described for conformal coating, and is particularly qualified to provide mechanical support and electrical insulation. Additionally, some foam materials are used sometimes to insulate components from external heat sources.

Potting can generate thermal problems, since embedded components can cool only by conduction until the heat reaches the potting surface, at which time, convection cooling can occur. The number of components in a single pot, their heat dissipation characteristics, their heat tolerance, and the heat transfer characteristics of the pot in the proposed design must be evaluated carefully.

b. Material Types and Application. There are three major types of potting compounds: epoxy resin formulations, polyurethane formulations, and room temperature vulcanizing silicone rubber compounds. Some less frequently used types are polystyrene and unsaturated polyester formulations. Literally hundreds, and perhaps thousands, of possible formulations of potting compounds are commercially available, with a resulting wide range of physical, thermal, and electrical properties.

Epoxy resins, because of their overall excellent electrical, mechanical, and physical properties, are the most widely used materials for potting of electronic modules and other assemblies of electronic components. The basic epoxy resin can be almost endlessly modified through the use of selected fillers, flexibilizers, modifiers, copolymers, and curing agents to make literally hundreds of different epoxy formulations. The epoxy formulations can vary from semiflexible compounds with low physical properties to hard, rigid materials with exceptionally high-strength properties. Almost all of the epoxy potting compounds are two-component materials that must be accurately mixed and properly cured. Some of the newer formulations are one-component materials that must be cured at high temperatures.

Polyurethane resins in the form of lightweight foams and as solid elastomers (rubbers) are used for potting of electronic modules and other assemblies of electronic components. In addition, a major usage for the solid elastometers is in the potting (molding) of cable connector terminations. Compared to the epoxies, very few polyurethane potting compounds are used. Basically, the most widely used polyurethane foams are in a density range of 2 to 10 lb per ft^3, and the solid elastomer materials are almost all compounds without fillers. Almost all of the polyurethane potting compounds (including the foams) are two-component materials that must be mixed accurately and cured properly (however, most of the two-component polyurethane elastomers can be purchased in frozen, premixed cartridges). One-component, high-temperature curing polyurethanes now are available commercially.

Silicone rubbers, seldom used for potting of modules and assemblies, are most widely used for potting of connectors, high-voltage equipment, and high-temperature devices. The silicone rubbers vary in hardness, and most but not all of the potting formulations contain fillers. Almost all of the silicone rubber potting compounds are two-component materials that must be accurately mixed and properly cured. One-component, high-temperature curing silicone rubber potting compounds are now commercially available. One-component, chemically blocked materials that cure at room temperature when exposed to atmospheric moisture occasionally are used as potting compounds, with depths restricted to a quarter inch or less.

Potting poses manufacturing problems that can be controlled with proper manufacturing processes. One type of problem results when, during curing, potting compounds shrink and set up stresses that cause embedded components to break. A second problem involves improper adhesive bonds between potting compounds and components. Items to be potted must be cleaned in the same manner as items that are to be conformal coated (see par. 3-4.7.2.1*b*).

c. Maintenance Considerations. Potting is used in the great majority of cases to fabricate modules that will be discarded at failure. It is extremely difficult and expensive to remove potting compounds.

d. Safety Considerations. The carcinogen MOCA is used widely in the preparation of polyurethane potting compounds. These potting compounds should be avoided (see par. 3-4.7.2.1*d*).

3-4.7.2.3 *Vibration Control*

Vibration is one of the most critical environments to which electronic equipment can be subjected. Vibration is transmitted through the materiel structure into the mounting system of the component packages. Such induced vibration normally will not harm properly designed equipment if amplification through the mounting system is held within reasonable limits. Because amplification takes place when components, housings, and mountings fall into resonance, a primary design requirement is to determine the critical resonant frequencies of the housing and component assembly. The housing and internal mounting arrangement must be designed so that resonant frequencies of housings and of critical internal components will not coincide. To minimize the effects of vibration, materiel design should be governed by the following principles:

a. Design the housings so that the center of gravity is as close as possible to the mounting surface.

b. Avoid any large, flat housing wall that acts as a diaphragm and amplifies vibration. Reinforce housing walls by using internal or external fins or ribs, or by adding mounting points, to minimize vibration amplification.

c. Use vibration mounts only when mandatory, because of additional problems incurred by heat transfer, electromagnetic interference bonding requirements, and cable interconnect considerations. If vibration mounts are required, select a mounting system with a natural frequency less than one-third of the critical frequency of the components to be housed. The mounts operate most effectively when installed in the plane of the center of gravity of the supported object.

d. When practical, use conformal coating or potting to support components and devices that would otherwise be subjected to vibration stresses.

e. Design subassembly structures (subchassis) as mechanically integrated assembly load-bearing members, and stiff enough to assure that component fragility levels are not exceeded. Insure that subassemblies are designed so that components, modules, and interconnecting devices are not damaged by deflections due to shock and vibration.

3-4.7.3 Test Points (Ref. 1)

All materiel must be maintained. This even applies to discard-at-failure modules, which cannot be discarded until their failures are ascertained, and this act in itself is maintenance, Therefore, testing provisions that permit the detection of actual or imminent failures must be provided for all materiel other than mechanical assemblies, which signal a catastrophic failure by an easily interpreted change in operating characteristics; e.g., the failure of a firing pin in a rifle, or a piston rod in an engine. Even in the case of mechanical equipment, it is highly desirable to have some testing method whereby an imminent failure can be detected and the item replaced before it fails catastrophically.

Selection of the test methods to be used is decided early in the materiel program for both mechanical and electronic equipment. The decision is based on trade-offs that involve operational requirements, the items to be tested, the types of test equipment that can be used, life cycle costs, etc. The physical phenomena to be tested will vary widely between electronic and mechanical materiel. General types of test equipment applicable to either materiel type are:

a. Special-purpose Test Equipment. Test equipment designed for a unique use pertaining to a particular system.

b. General-purpose Test Equipment. Test equipment usable in different systems; generally available as an "off-the-shelf" item in Government or commercial inventories.

c. *Built-in Test Equipment.* Equipment that is an integral part of the primary equipment or system; cannot be readily detached or separated from basic equipment. Normally typified by "press-to-test" procedures.

d. Automatic Test Equipment. Equipment considered to be separate from the system to be tested. Capable of automatically testing and evaluating many test parameters by providing required input stimuli.

A final step in implementing test equipment decisions is to construct materiel with adequate test points. The test points must be compatible with the test equipment to be used, must provide for a connection between the test equipment and the phenomena to be measured, and must optimize the interfaces among' man, test equipment, and test points.

3-4.7.3.1 Electronic Materiel Test Points

A test point provides a convenient and safe access for examining a significant parameter of a circuit in order to facilitate maintenance, repair, calibration, and alignment. Strategically placed test points provide a technician with a practical means of examining the operational status of the equipment.

a. Classification. Test points consist, in general, of the following types:

(1) *Major.* Test points provided for checking the overall performance of and localizing trouble in groups of major electronic or electromechanical units.

(2) *Intermediate.* Test points provided for checking the performance of and localizing trouble in equipment groups, major units, and subassemblies.

(3) *Minor.* Test points provided for checking performance of and localizing trouble in specific circuits of a major unit or subassemblies.

(4) *Exposed Point.* Test point that is readily accessible when the equipment is in normal operating condition and position.

(5) *Accessible Point.* Test point that is accessible without the use of tools, but which is not exposed.

(6) *Special Point.* Test point that is accessible only by the use of tools or other special means.

b. Functional Location. The specific test points to be used in an electronic system should depend upon the operational and tactical demand placed on the system design, and the special needs of a particular service. The numbers and types of test points should be compatible with the test instrumentation (built-in or otherwise) available at the place of system use, or at the maintenance or repair activity.

The functional locations of test points should be fixed by determining from the maintenance procedures the signals that must be available to the technician and the points at which they must be available. Test points should make available those signals that the procedures indicate the technician must have in order to maintain the system. Their locations must be planned into the system for maximum effectiveness.

It should not be necessary to remove any assembly from a major component to troubleshoot that assembly. This may require special test points on the major components or assemblies. Also, test equipment and bench mockup access to the outputs and inputs of each line replaceable unit should be provided through normal interconnecting plugs whenever possible.

c. Physical Location. The physical locations of test points have a marked effect on the quality **of** maintenance. Generally, all test points should be grouped in one area. In some cases, previously developed equipment may have to be used, or the nature of a signal may be such that it does not travel well without being altered in the process of transmission. The designer should keep in mind that the technician needs only an indication that reflects an out-of-tolerance condition of the true signal. If the indications are checked and recorded during engineering tests, they should be adequate for field use. This consideration is particularly pertinent in those cases where the wave shape of the signal is critical and will tend to change in transmission to a test point.

Test points should be accessible in the particular installation. Internal test points should be clustered around the portion of the unit that will be most accessible when installed. Only one adjustment control should be associated with each test point, and it should be easily and reliably operated.

d. Arrangement. Selector switches on materiel with built-in test equipment, and test points on all other materiel, should provide for logical, sequential testing. In the case of test points, this is accomplished by their being arranged in proper sequence on a panel.

(1) *Built-in Test Unit.* An arrangement built in as part of the installation is most desirable for efficient maintenance and troubleshooting. For example, if voltages and wave shapes must be checked, the test unit might consist of a meter, an oscilloscope, and a rotary switch for selecting circuits. If more test points are needed than can be handled by a single switch, multiple switches can be used.

(2) *Partially Built-in Test Unit.* Because some oscilloscopes are large, heavy, and expensive, it might not be practical to design a built-in test unit for each major component of a system. An acceptable compromise is to mount a center-reading meter on each major component that can be checked by meter, and then provide a set of test jacks as an outlet for signals requiring an oscilloscope. The rotary selector switch and circuits for this arrangement should be designed the same as those for the built-in test unit.

(3) *Portable Test Unit.* If neither of the two previously described arrangements is practicable because of space or weight limitations, an integrated portable test unit resembling the built-in unit can be designed. A single multiprong contact on the end of a cable can be used to attach the test unit.

(4) *Built-in Test Panel.* If, for some reason, none of the previously described alternatives is practicable, a test panel can be provided on the equipment. With this arrangement, the outputs of each test point should be designed for checking with standard test equipment, and the points should be planned to provide a miniature block diagram of the system, with each block representing a line replaceable unit. Overlays for the test panel should direct the technician to test points he should check, and the order in which he should check them. In-tolerance signals should be shown on the overlays, and test points should be coded on the panel, with full instructions provided in the maintenance manual in the event the overlay is lost.

(5) *Test Points on Replaceable Units.* If none of the four previously described arrangements is practicable, test points for the inputs and outputs can be provided on each replaceable unit. These should provide for complete testing in order to avoid the undesirable alternative of troubleshooting by part substitution.

e. Labeling. The following design recommendations should be observed for test point labeling:

(1) Label each test point with a number, letter, or other symbol that identifies it in the maintenance instructions.

(2) Label each test point with the in-tolerance signal and, if possible, the tolerance limits of the signal that should be measured at that point.

(3) Include the name of the unit in the label, if possible.

(4) Consider color-coding test points so that they can be located easily.

(5) Use phosphorescent or chemoluminescent markings on test points, selector switches, and meters that might have to be read at very low levels of illumination.

All test point labeling information should be completely reflected in technical publications.

f. Test Point Checklist. Table 3-6 summarizes some of the important features pertaining to the design of test points. The checklist contains several items that have not been discussed separately in the text. These items are included in Table 3-6 because their necessity in the design is so obvious that they might otherwise be inadvertently overlooked. In using the checklist, if the answer to any question is no, the design should be restudied to ascertain the need for correction.

3-4.7.3.2 Mechanical Materiel Test Points

Built-in test equipment has not been used as extensively in mechanical, electromechanical, hydraulic, etc., equipment as in electronic equipment. Built-in test equipment simply was not cost-effective with the technology that existed. With current technology, the use of built-in test equipment in mechanical equipment—automobiles, for example—is increasing.

Regardless of whether mechanical test equipment is built-in or separate, mechanical equipment test points must provide for measurement of the same parameters. The variety of physical phenomena that must be measured is extensive. This is demonstrated by Table 3-7, which lists typical measurements required for the diagnosis of spark ignition and compression ignition internal combustion engines.

TABLE 3-6. TEST POINT CHECKLIST

1. Are test points located on front panel when possible?
2. Is accessibility of external test points assured under use conditions?
3. Are test points grouped for accessibility and convenient sequential arrangement of testing?
4. Is each test point labeled with name or symbol appropriate to that point?
5. Is each test point labeled with in-tolerance signal or limits that should be measured?
6. Are test points labeled with designation of the output available?
7. Are all test points color coded with distinctive colors?
8. Are test points provided in accordance with the system test plan?
9. Are test lead connectors used that require no more than a fraction of a turn to connect?
10. Are test points located close to controls and displays with which they are associated?
11. Is test point used in adjustment procedure associated with only one adjustment control?
12. Are means provided for an unambiguous signal indication at test point when associated control has been moved?
13. Are test points located so that technician operating associated control can read signal on display?
14. Are test points provided for direct check of all replaceable parts?
15. Are fan-out cables in junction boxes used for checking if standard test points are not provided?
16. Are test points planned for compatibility with the maintenance skill levels involved and not randomly located?
17. Are test points coded or cross-referenced with associated units to indicate locations of faulty circuits?
18. Are test points provided to reduce number of steps required (i.e., split-half isolation of trouble, automatic self-check sequencing, minimizing of step retracing or multiple concurrent tests)?
19. Are test points located so as to reduce hunting time (near main access openings, in groups, properly labeled, near primary surface to be observed from working position)?
20. Are test points that require test probe retention provided so that technician will not have to hold the probe?
21. Are built-in test features provided wherever standard portable test equipment cannot be used?
22. Are test points adequately protected, illuminated, and accessible?
23. Are routine test points located so that the technician does not have to remove the chassis from the cabinet?

TABLE 3-7. DIAGNOSTIC MEASUREMENTS FOR INTERNAL COMBUSTION ENGINES

Measurement	Type of Engine	
	Spark Ignition	Compression Ignition
1. Intake manifold pressure	X	
2. Engine speed/camshaft angle	X	X
3. Fuel rate	X	X
4. Ignition waveform	X	
5. Engine torque	X	X
6. Airflow	X	X
7. Exhaust analysis	X	X
8. Injector pump pressure	X	X
9. Exhaust blowby	X	X
10. Oil consumption	X	X
11. Cylinder power drop	X	
12. Oil pressure (engine)	X	X
13. Oil temperature	X	X
14. Battery voltage and charging current	X	X
15. Starter drain	X	X
16. Lower crankcase vibration	X	X
17. Coolant temperature, inlet/outlet	X	X
18. Transfer vibration	X	X
19. Differential vibration	X	X
20. Electrical subsystem	X	X
21. Compression pressure	X	X
22. Cylinder head temperature	X	
23. Fuel pump pressure	X	X
24. Cooling system pressure	X	X
25. Lubricant level	X	X
26. Exhaust gas temperature	X	X
27. Pressure ratio (turbo charger)		X

For separate test equipment, test point access to physical phenomena such as fluid pressures, flows, and temperatures may be gained in one of two general ways. One method is to design the fluid conduit so that a section can be removed and an instrumentation section inserted. The other method is to provide an access port in the fluid conduit to which instrumentation may be attached. The first method is applicable to light, accessible, and easily removed sections such as sections of fuel lines. The other method is applicable to conduits, such as engine coolant conduits, that would be troublesome to remove and replace. Rotation and vibration data normally are obtained by attaching instrumentation at predetermined points to the surface of assemblies. The principles described for electronic materiel test points apply to electrical systems of mechanical materiel.

Test points for built-in test equipment require the "permanent" installation of sensors and transducers in appropriate locations. Such test points also can be installed and used with separate test equipment, thus reducing test setup and cleanup times.

As with all materiel design features, test points and test equipment should have no more complexity than is required to satisfy operational requirements. For example, an access port and a dipstick or a fill and inspection port is perfectly adequate for determining many fluid levels. Providing test equipment and its associated test points to accomplish these functions would not be cost-effective under normal circumstances. Virtually any physical phenomenon can be measured. The objective is to measure the smallest possible number of phenomena in a manner that will result in a savings in life cycle costs.

3-4.7.4 Indirect Testing

Many mechanical components subjected to continuous operating friction are not easily accessible because state-of-the-art mechanical packaging techniques do not permit such accessibility. Examples of this are vehicle components such as differential gears and crankshaft bearings. Such components are subject to wearout rather than random failure. Wearout failures generally occur in time according to a normal or Gaussian distribution (the bell curve). This fact and other data can be used to calculate an average expected life for the components and, prior to this time, component replacement can be scheduled.

Unfortunately, the average expected life is just that, and is comprised of the lives of components which, if not replaced, will become functionally impaired before and after the average life span. If it is assumed that a replacement practice is based on average expected life, some components will fail before the scheduled replacement, and many will be replaced that would have continued to perform satisfactorily for varying periods of time. Such ineffective and wasteful scheduled maintenance can be avoided by indirectly measuring the wearout that components are experiencing without disassembling the assemblies in which they are located and replacing only those that are approaching an unsatisfactory condition.

Indirect measurement of the wear of inaccessible components in aircraft is being accomplished by the Army through spectrometric oil analysis. This technique has proven to be quite cost effective, and it will probably be applied to other materiel in the future. Similar results could be obtained with radioactive tracer techniques. In this case, the components of interest would be irradiated and the quantity of metal molecules deposited by friction into surrounding lubricant would be measured with radiation instrumentation.

Maintenance engineering should maintain current knowledge of all state-of-the-art indirect measurement techniques and consider their application, when appropriate, to new and existing materiel. For materiel deployed in large quantities, a very large initial investment is warranted to establish a capability to detect imminent failures, thereby increasing materiel availability and safety, and at the same time avoiding the accomplishment of unnecessary maintenance,

3-4.7.5 Bearings (*Ref.* 1)

Because bearing maintenance and bearing failures account for the largest percentage of maintenance costs for mechanical products, selection of the proper sizes and types of bearings can be considered one of the most important of all design considerations. The total life span of mechanical items more often is limited by the life of its bearings than by failure of any other parts.

The proper bearing for a specific application is the one that:

a. Requires the minimum life cycle cost.

b. Requires little or no maintenance (lubricating, adjusting, etc.).

c. Requires little or no periodic inspection

d. Permits the most rapid inspection.

e. Satisfactorily overcomes manufacturing, operating, or aging misalignment problems.

f. Performs satisfactorily for the life of the product.

3-4.7.5.1 *Nonlubricated Bearings*

Bearings requiring no lubrication or maintenance should be used whenever possible. Such bearings are made of synthetic rubber, nylon, Teflon, and fiber. This type of bearing should be given first consideration in such applications as instrument bearings, leaf spring ends, pushrod ends, drive shaft universal joints, and fuel valve bearings.

3-4.7.5.2 Semilubricated Bearings

In bearing applications where the materials used for nonlubricated bearings are unsuitable, the use of oil-impregnated, sintered bronze (or similar) bearings may be considered. Such bearing assemblies should include contaminant-excluding seals when they are used in locations where destructive contaminants may be present. For ease of servicing, an easily accessible oil service point, sealed with a plug or oil cup and properly marked, should be provided.

3-4.7.5.3 Sealed Bearings

In applications requiring a high load-carrying capacity with minimum space requirements, bearings containing their own supply of lubricants are highly desirable. The lubricant is retained by seals on one or both sides of the bearings. However, even though these types of bearings are "sealed for life" they should be provided with some means of .external relubrication. Such relubrication, when necessary, may be difficult; for example, the "oil hole" may have to be made through a synthetic seal pierced with a hypodermic needle, or an entrance may have to be drilled in the bearing, leading out through the housing to an easily accessible position. Regardless of the method selected, the loss of lubricant back through the "oil hole" or the entrance of contaminants into the lubricant must be avoided.

3-4.7.5.4 Sleeve Bearings

Probably no one factor of past design has contributed more to premature equipment aging or costly maintenance than the widespread use of solid metal sleeve bearings. These bearings, in general, never provide for wear, but progressively grow worse with use and seldom provide any means of compensating for this wear. Therefore, the use of solid metal, nonporous sleeve bearings in any application should be questioned in every case. In applications where sleeve bearings are used, however, high-pressure lubrication should be supplied to the bearing surface whenever possible.

3-4.7.5.5 Straight Roller Bearings and Ball Bearings

The use of straight roller and ball bearings which are not adjustable and do not provide wear-compensation should be confined to applications where:

a. The bearing size, load-carrying capacity, and operating speed are such as to guarantee that the bearing will outlive the service life of the product.

b. Needle bearings operate against shafts of at least 40 Rockwell C scale hardness.

c. They operate in an enclosure having a constant supply of lubricant.

d. They conform to applicable Federal and Military Specifications.

e. No other type of bearing will perform the task more suitably.

Roller bearing life is determined by the fatigue life of raceways and rollers if proper attention has been given to the details of lubrication and mounting, and to the exclusion of foreign material.

3-4.7.5.6 Tapered Roller Bearings

Tapered roller bearings, when suitable for design, represent the optimum in bearing maintainability and, therefore, should be given high priority in the selection of bearings. The fact that they are occasionally higher in initial cost should be weighed against the cost of replacement of another type of bearing throughout the life cycle of the product.

Tapered roller bearings may be adjusted by using threaded, lockable components, or by shims. Whenever possible, the threaded adjusting method should be used to eliminate the necessity for stocking shims. Regardless of the method of adjusting, however, bearing housing design should allow the easiest and simplest access to the adjustment.

3-4.7.5.7 Bearing Seals

Seals used to retain lubricants in bearing housings having protruding, rotating, and sliding shafts and axles should be given specific and special considerations in the design of equipment. Some of these considerations are:

a. Seals should reflect the highest quality in design and material concurrent with the state of the art for its intended service.

b. Seal housing design should provide the optimum of simplicity for replacement of the seals by inexperienced personnel operating in the field. If possible, no special tools, including wheel pullers, should be required for replacement of bearing seals.

c. The use of blind fittings and fasteners should be avoided.

d. Consideration should be given to the use of multiple-lipped seals and double and triple seals, each element of which is capable of fulfilling the sealing requirements alone.

e. When design will permit their use, prime consideration should be given to the use of spring-loaded, positive-contact end seals.

f. Each design should be examined to insure that the seal will not be damaged by excessive internal pressure. When the possibility of excessive pressure exists, due to heat expansion of the lubricant or other causes, a relief valve should be installed (as appropriate) on the housing, and a return line to a sump should be installed, when appropriate.

3-4.7.5.8 Derating

All bearings should be derated to insure that their capabilities have dynamic factors of safety. This factor of safety is necessary to prevent overload conditions not readily apparent in new applications or due to unexpected service conditions. Derating also provides longer bearing life, with less required maintenance and increased maintainability. As a general rule, bearings should be derated to the maximum extent permitted by cost, performance, weight, or space provisions.

3-4.7.6 Lubrication (Ref. 1)

Lubrication of materiel is of vital importance. The best designed ,equipment, viewed from combat efficiency, performance, maintainability, and reliability standpoints, can and does fail completely due to inadequate and improper lubrication. In many items, lubrication is the only maintenance required for long maintenance-free service. Equipment designs sometimes are produced with little thought given to the vast number of maintenance hours required in the field for periodic lubrication and checking of oil levels. Rapid lubrication capability should be built into the equipment and the design of this capability should be considered to be as important as the proper functional design of the equipment. Particular attention to lubrication requirements should be given to electronic and electrical equipment. Poorly lubricated synchros, switch shafts, generators, motors, and relay arms have been a serious source of malfunction that has resulted in destruction of the equipment.

Working surfaces subject to wear or deterioration should be provided with appropriate means of lubrication. Commercial grade lubricants should be used whenever possible. Equipment should be designed to use only one type of oil and one type of grease. When this is not practical, the types and grades should be kept to a minimum. When a special lubricant is required to satisfy unusual operational requirements, such as high- or low-temperature operational environments, each lubrication fitting having this requirement should be clearly labeled with letters 0.25 in. high, giving the grease or oil specification and placed as close to the fitting as is suitable.

Lubrication, besides reducing friction and wear between moving parts, also can serve as a seal to exclude undesirable substances from the area being lubricated, and act as a carrier for rust preventives, antifriction agents, extreme pressure additives, etc. Additionally, lubricants provide a means of removing waste products or contaminants. For example, in engines, the products of combustion, sludge, and acids collect in the crankcase oil and are removed when the oil is changed periodically. Correct lubrication is an important factor in obtaining good performance from many parts.

When sealed bearings or semilubricated bearings are used, the lubricants selected should have the optimum state-of-the-art characteristics for protection against deterioration from age. This requirement is particularly important to items liable to long, inactive storage where deterioration could cause destruction of lubricating properties. Whenever possible, lubricants also should be capable of satisfactory service at ambient temperatures ranging between −67° and 250°F.

3-4.7.7 Fixed Joints

Frequently, there is a requirement for two mechanical assemblies to be mechanically attached to each other and to move with respect to each other. An example of this is a vehicle propeller shaft, which provides a power drive between sprung and unsprung vehicle assemblies. A capability for relative movement is provided by one or more joints in the shaft, which require some type of lubrication. Since even lifetime lubricants and seals may not last throughout the life cycle of the vehicle, one is faced at best with a potential maintenance problem.

In many cases, it is possible to provide mechanical connection and a capability for relative movement with fixed joints that will never require lubrication. Two vehicle components that connect sprung and unsprung assemblies are torsion bars and coil springs. Other examples are flexible power drive shafts, flexible couplings, and power drive belts as opposed to chain belts.

Even though lubrication requirements may be eliminated by substituting a fixed joint for a moving one, it does not follow that the fixed joint is always the correct choice. Each application must be subjected to a life cycle cost analysis. For example, the higher cost of a chain belt as compared to a conventional belt, and the cost of lubricating the chain belt, might be more than offset by the cost of the conventional belt plus the cost of replacing it several times during the materiel life cycle.

3-4.7.8 Self-adjusting Components

The requirement for maintenance adjustments can be reduced significantly by designing materiel with self-adjusting features. A prime example of such an assembly is self-adjusting brakes. Other examples are self-adjusting valves for internal combustion engines, electrical brushes, and belt and chain power transmission assemblies that incorporate a spring-loaded idler pulley or sprocket.

3-4.8 CORROSION ASPECTS

Corrosion is a potential source of materiel failure and of requirements to expend significant quantities of maintenance resources in corrosion control efforts. These potential problems can be avoided or alleviated by the proper selection of materials and material- protective coatings.

3-4.8.1 Material Selection

Corrosion can result from galvanic action, chemical reactions, stress, and other causes. In general, galvanic corrosion and chemical corrosion are the greatest threats to Army materiel. Galvanic corrosion occurs when two dissimilar metals are in electrical contact and are exposed to a common electrolyte. In such a case, a galvanic cell is formed, and the material functioning as the anode will corrode rapidly. Chemical corrosion is the direct action of one material upon another to produce a new compound. Oxidation is a common and troublesome form of chemical corrosion that results in oxides that are called rust on iron alloys and sometimes are called rust on other metals. Oxidation (rust formation) is accelerated by the presence of water and is a significant problem for materiel such as combat vehicles and automotive equipment that must function in an unprotected environment.

Metals are categorized into groups by electrochemical potentials that reflect the magnitude of the galvanic corrosion that can occur if dissimilar metals are joined. Such a galvanic series is shown in Table 3-8. Dissimilar metals far apart in the series should not be joined directly together. If they must be used together, insulating material or protective coatings must be used. In the absence of dissimilar metals, limited galvanic action can sometimes occur because of irregularities on a single metal surface, but this is not a significant problem.

For applications where dissimilar metals are not involved, the galvanic series provides incomplete guidance in material selection; i.e., a few of the more anodic metals are acceptable. For example, the metals most commonly used in vehicle design for their corrosion resistant properties are:

Titanium	Chromium
Molybdenum alloys	Zinc
Stainless steel	Nickel
Pure aluminum	Tin
Cadmium	Copper alloys

3-4.8.2 Protective Finishes

Careful consideration of the many factors involved in the proper selection of protective

TABLE 3-8. GALVANIC SERIES OF METALS AND ALLOYS (Ref. 1)

Group	Metal
Anodic End (most easily corroded)	
I	Magnesium
	Magnesium alloys
II	Zinc
	Galvanized iron or steel
	Aluminum (5058, 5052, 3004, 3003, 6063, 6053)
III	Cadmium
	Cadmium plated iron or steel
	Mild steel
	Wrought iron
	Cast iron
	Ni resist
	Lead-tin solders
	Lead
	Tin
IV	Chromium
	Admiralty brass
	Aluminum bronze
	Red brass
	Copper
	Silicon bronze
	Phosphor bronze
	Beryllium copper
	Nickel
	Inconel
	Monel
	Type 400 corrosion resisting steel
	Type 300 corrosion resisting steel
	Titanium
V	Silver
	Gold
	Platinum
Cathodic End (least susceptible to corrosion)	

finishes for metals at the outset of design will result in optimum production costs and reduced operational maintenance requirements. No one metallic coating and application technique is best for every application.

3-4.8.2.1 finish Selection Considerations

Finishes cannot be selected until operational, functional, and manufacturing problems are defined.

a. Service Enuironment. The anticipated service environment should be defined to include factors such as:

(1) Temperature range
(2) Humidity
(3) Rain
(4) Salt and spray
(5) Dust and sand
(6) Industrial smog
(7) Direct sunlight

b. Functional Considerations. The finish selected should be best suited for the base material and its function and environment. Factors that must be considered include:

(1) Corrosion resistance (including galvanic effects)
(2) Solderability
(3) Conductivity
(4) Hardness
(5) Wear resistance
(6) Antifriction properties
(7) Heat reflectivity and emission
(8) Nonsupport of fungi (nonnutrient)
(9) Moisture repellant
(10) Color (appearance)

c. Manufacturing Considerations. Manufacturing processes are interdependent with finish selection. Factors to be considered include:

(1) Critical dimensions may dictate the type of finish selected.

(2) Corners, recesses, and holes must be designed in consideration of the throwing power of plating, as well as the application and drainage of rinses and liquid finishes.

(3) If a coating thickness greater than 0.0002 in. is specified for threaded and close-tolerance items, allowance must be made in the part dimension for buildup when the part is plated.

(4) If dissimilar metal contacts cannot be avoided, plated finishes should be selected to provide a cathodic small surface in contact with an anodic larger surface.

(5) Because of uneven current distribution, electrodeposited coatings on corners, edges, and protruding areas will be many times thicker than on flat surfaces, but deposits in recessed areas will be thinner. To assure adequate coating thickness over the low-current density areas while at the same time avoiding excessive thickness on the high-current density areas, consideration should be given during the design stage to minimizing sharp corners, recesses, blind holes, etc.

(6) Many electroplated coatings are by nature porous or cracked. For maximum protection, a multilayer coating system should be specified to. provide a more impervious barrier. Three thin layers give better protection than one layer of the same total thickness. Minimum thickness always should be specified.

3-4.8.2.2 Types of Finishes

Finishes are categorized as organic or inorganic.

a. Organic. Organic finishes generally give better corrosion protection than inorganic finishes and, in addition, offer a wide range of decorative appearance such as color and luster. When the design permits, organic finishes should be specified. Organic finishes are classified as paints, lacquers, enamels, varnishes, and drying oils. In addition, there are resin base organic finishes that cure by a chemical reaction in the presence of a catalyst or heat, or both.

b. Inorganic. Inorganic finishes are protective metal coatings applied by electroplating, flame spraying, hot dipping, etc., and chemical or electrochemical conversion coatings such as anodize, iridite, and passivation. Some examples of finishes commonly used on several metals are listed in Table **3-9.**

TABLE 3-9. PROTECTIVE FINISHES FOR VARIOUS METALS (Ref. 1)

Material	Finish	Remarks
Aluminum alloy	Anodize	An electrochemical-oxidation surface treatment for improving corrosion resistance; not an electroplating process. For riveted or welded assemblies, specify chromic acid anodizing. Do not anodize parts with nonaluminum inserts.
	Anodize (Martin hardcoating)	Much harder than normal anodize with superior wear properties. Has been used for missile launcher rails in conjuction with solid-film lubricants for its wear-resistant qualities. Suitable for building up undersized parts.
	"Alrok"	Chemical-dip oxide treatment. Cheap. Inferior in abrasion and corrosion resistance to the anodizing process, but applicable to assemblies of aluminum and nonaluminum materials.
Copper and zinc alloys	Bright acid dip	Immersion of parts in acid solution. Clear lacquer applied to prevent tarnish.

TABLE *3-9*. PROTECTIVE FINISHES FOR VARIOUS METALS (Ref. 1) (Cont'd)

Material	Finish	Remarks
Brass, bronze, zinc diecasting alloys	Brass, chrome, nickel, tin	As discussed under steel.
Magnesium alloy	Dichromate treatment	Corrosion-preventive dichromate dip. Yellow color.
	Anodize	Dow Chemical Company developed process used extensively for aircraft parts.
Stainless steel	Passivating treatment	Nitric acid immunizing dip.
Steel	Cadmium	Electroplate; dull white color, good corrosion resistance, easily scratched, good thread antiseize. Poor wear and galling resistance.
	Chromium	Electroplate; excellent corrosion resistance and lustrous appearance. Relatively expensive. Specify hard chrome plate for exceptionally hard abrasion-resistant surface. Has low coefficient of friction. Used to some extent on nonferrous metals, particularly when diecast. Chrome-plated objects usually receive a base electroplate of copper, then nickel, followed by chromium. Used for buildup of parts that are undersized. Do not use on parts with deep recesses.
	Blueing	Immersion of cleaned and polished steel into heated saltpeter or carbonaceous material. Part then rubbed with linseed oil. Cheap. Poor corrosion resistance.
	Silver plate	Electroplate; frosted appearance, buff to brighten. Tarnishes readily. Good bearing lining. For electrical contacts, reflectors.
	Zinc plate	Dip in molten zinc (galvanizing) or electroplate of low-carbon or low-alloy steels. Low cost. Generally inferior to cadmium plate. Poor appearance and wear resistance. Electroplate has better adherence to base metal than hot-dip coating. For improving corrosion resistance, zinc plated parts are given special inhibiting treatments.
	Nickel plate	Electroplate; dull white. Does not protect steel from galvanic corrosion. If plating is broken, corrosion of base metal will be hastened. Finishes in dull white, polished, or black. Do not use on parts with deep recesses.

TABLE 3-9. PROTECTIVE FINISHES FOR VARIOUS METALS (Ref. 1) (Cont'd)

Material	Finish	Remarks
Steel (Cont'd)		
	Black oxide dip	Nonmetallic chemical black oxidizing treatment for steel, cast iron, and wrought iron. Inferior to electroplate. No buildup. Suitable for parts with close dimensional requirements, such as gears, worms, and guides. Poor abrasion resistance.
	Phosphate treatment	Nonmetallic chemical treatment for steel and iron products. Suitable for protection of internal surfaces of hollow parts. Small amount of surface buildup. Inferior to metallic electroplate. Poor abrasion resistance. Good point base.
	Tin plate	Hot dip or electroplate. Excellent corrosion resistance, but if broken will not protect steel from galvanic corrosion. Also used for copper, brass, and bronze parts that must be soldered after plating. Tin-plated parts can be severely worked and deformed without rupture of plating.
	Brass plate	Electroplate of copper and zinc. Applied to brass and steel parts when uniform appearance is desired. Applied to steel parts when bonding to rubber is desired.
	Copper plate	Electroplate applied preliminary to nickel or chrome plates. Also for parts to be brazed or protected against carburization. Tarnishes readily.
	Gold plate	Electroplate, gold color, resists corrosion and color change. For electrical and electronic applications.

3-4.9 DURABILITY CONSIDERATIONS

Durability may be defined as the capability of a system, assembly, subassembly, or component to meet ,or exceed its life expectancy by virtue of its design and construction with a minimum of upkeep or repair requirements. Life expectancy is defined as the projected service life, or time to a planned overhaul or rebuild point. Durability also may be defined as the probability that an item successfully will survive its projected service life, overhaul point, or rebuild point without a catastrophic failure. In this application, catastrophic failure is defined as a failure that requires the item to be replaced or rebuilt.

Life expectancy or projected service life is expressed in measurable units such as miles, number of specified events, and time. Some examples of life expectancy are: automobile tire, 25,000 mi; toggle switch, 20,000 cycles; push-button switch (nonsnap action), 2,000,000cycles; automotive vehicle 14 yr and/or 70,000 mi; and missile system, 10 yr. Life expectancy values are based on the assumptions that items will not be subjected to natural and induced environments more severe than those for which they were designed and that preventive and corrective maintenance will be performed in accordance with established procedures.

Durability is the end result or culmination of the activities of a multitude of disciplines that determine the probability of a system to survive to its projected service life or rebuild point. These disciplines include but are not limited to design, manufacturing, quality control, reliability, and maintainability. Durability requirements relate primarily to design, production, logistic burdens, and life cycle costs, and should be based on cost trade-off studies. Tradeoffs between reliability and maintainability can be utilized to optimize life cycle costs while improving durability. The ideal system should be designed to meet its functional requirements, and should be durable and reasonable in cost.

While reliability is primarily concerned with avoiding failure and maintainability is concerned with corrective and preventive maintenance, durability is primarily concerned with wearout. A durable system can survive to its projected service or rebuild point with normal maintenance support. Normal maintenance support is the preventive and corrective maintenance activities described in the maintenance plan.

Durability provides a means for evaluating the *total* system and all the disciplines involved in assuring that the system will function within the designed specifications and limitations for the intended service life. It also can be a powerful discipline in predicting the useful service life of a system. Reassessing durability can optimize the rebuild/overhaul cycle, extend the service life, and result in minimized cost.

Theoretically, a system with perfect durability would survive to the last day of its planned service life or to its planned rebuild or overhaul point, and have little or no remaining capability. Actually, durability cannot be designed into materiel with such precision. Frequently, materiel will be more durable than was predicted. Therefore, periodic assessments of durability should be conducted to determine whether or not service life or the rebuild point can be extended. For example, the Army conducted a life extension and assessment program on a missile system and determined that missile service life could be greatly extended with some minor modifications and some changes in maintenance procedures. Considering the fact that the alternative could have been to manufacture new missiles, significant costs were avoided.

Durability provides a means for optimizing the design and manufacturing process. A system may be overdesigned for the intended service life, resulting in excessive costs. Design may specify tolerances that significantly increase manufacturing costs and decrease durability. Test tolerances that are too stringent for a particular application may result in rejections prior to the expiration of the designed service life or rebuild point, thereby reducing durability. Increased durability reflects optimization of the design, production, and maintenance disciplines.

3-4.9.1 Improving Durability

Durability can be improved by optimizing design and production to insure that excessive wear or deterioration does not affect the projected service life or rebuild point. The type of materials used should be examined closely, with consideration given to size and weight dependent upon the particular application. Tolerances should be examined closely to determine the effect that tightening or relaxing tolerances would have on the longevity of the equipment under use. In some applications, relaxed tolerances may not only be more cost-effective because of simplified and more expedient manufacturing processes, but may also improve durability. Quality control procedures also should be examined for impact on improving durability.

3-4.9.1.1 *Selection of Materials*

The durab'ility of material is essentially a measure of its strength over an extended period of time. It is determined by the physical resistance of the material to deformation under stress during prolonged usage and, where applicable, material resistance to deterioration in a sustained corrosive atmosphere. In order to optimize durability, careful consideration should be given to the material selected for each particular application.

The properties of the material selected should be analyzed carefully. Some materials are used in a fairly pure form. While they may be altered by heat treatment or work hardening, no additional substances a're added. Failures may occur due to the addition of an extraneous substance, as in oxidation, or by applying energy in excess of the maximum storage level, such as friction heating. Other applications of materials require carefully controlled trace amounts of an impurity that greatly influence performance behavior. Failure of these materials under prolonged load will be hastened if there are changes in the concentration or distribution of the impurity. Higher purity of raw materials, special additives during the refining step, better design, or improved fabrication techniques all can be the basis for achieving greater product longevity.

Strength and durability are not always gained by heavy construction. In some cases, the elimination of massive sections improves ultimate strength and durability. Computer techniques for optimizing the size and shape of construction members have provided lightweight, simplified, and more cost-effective designs that also increase durability (see Ref. **20).** Reliability and longevity of machinery and structures are a function of a variety and multitude of parameters.

3-4.9.1.2 Tolerances and Fits

Another important factor to be considered for improved durability is the selection of manufacturing tolerances. Tolerances are assigned to the dimensions of parts and equipment and to the values of test specifications in order to define permissible limits. The tolerances and fits selected must be a trade-off involving the function of the component within the system, the accessibility of the component for maintenance or replacement, and the cost of manufacture.

Closer tolerances may increase system durability and reliability, but may be unacceptable due to unreasonably high manufacturing costs and higher rejection rates at inspection. Relaxed tolerances lower manufacturing costs, but may increase maintenance costs due to increased wear and resultant early replacement. Tolerances and fits should be determined by a detailed analysis and evaluation of the particular application. Operating conditions and the length of service should be examined. Closer tolerances to increase the reliability of inaccessible components such as seals, bearings, and sealed units should be paramount in importance, especially when the failure of that component would have a dramatic effect on the service life or planned overhaul point for the system involved.

The adverse effect of tightening tolerances also should be considered carefully. Close tolerances, and especially wear limits, may falsely indicate the end of the useful service life of a component or system, when, in fact, that system may be capable of performing its designed function throughout an extended service life, provided the functional tolerances or wear limits were relaxed. This is ample justification for periodic reassessment of the durability of a system during the service life to optimize overhaul/rebuild policies and minimize cost.

3-4.9.1.3 Quality Control

Quality control procedures should be reviewed continually and reevaluated to improve durability. Refinements in the quality control organization and procedures are frequently needed to assure maximum effectiveness. The use of intensified quality inspections during the manufacturing process and intensified quality acceptance tests can have a profound effect on system durability.

3-4.9.2 Testing Durability

All component design, to a large degree, must depend on the results of experimental testing. A number of well-known testing modes are in common use. Applying a steadily increasing stress to a sample of material will provide valuable yield data relative to sizing and establishing safety factors. Subjecting the finished component to continued operation at normal stress levels provides information on wearout (fatigue). Several considerations can complicate the assessment of the true durability of a component. Stress level, for example, constitutes an important element in interpreting the significance of yield and wearout test data. If test and application stress levels differ significantly, laboratory data may have little validity for use in design.

In 'wearout, age, and deterioration testing,, it is often found that the mean time to failure is too great in real time for practical evaluation. In this case, it is necessary to use accelerated testing conditions that greatly reduce the time necessary for testing. The design of an accelerated test and the interpretation of the data obtained require an understanding of the relation between stress level and the rate of the particular destructive process under consideration. For component wearout testing, the problem is relatively simple. The converse is true in designing tests or using analytical procedures to determine the service life or overhaul point for a weapon system. It is particularly difficult to design or evaluate the service life of a standby system, such as a missile system, whose application is more or less a static mode of readiness.

One approach to assessing the durability or predicting the service life of a component or system is to investigate the wearout time by analyzing the predicted or observed materiel "bathtub" curve (Fig. 3-4). The constant failure rate region marks a period of useful life. The termination of useful (service) life or time to wearout (overhaul point) may be selected at any point along the curve in the wearout region. Selection of the optimum time for termination of service life or conduct of overhaul maintenance must be based upon the particular application involved, the shape of the life characteristic curve, and the maximum failure rate that can be tolerated for the system under consideration.

Durability can be predicted by determining the maximum failure rate that is acceptable in the wearout region, applying it to the "bathtub" curve, and observing the indicated time. The wearout region can be identified by the sharp rise in the failure rate after the useful life period has terminated. This is due to the fact that two forces are then at work: chance (random) failures, and wearout failures.

Durability should be reassessed throughout the service life of the component or system. This reassessment is important, since the "bathtub" curve will shift or the shape will change when subunits or parts are replaced and normal maintenance activities occur.

3-4.9.3 Designing for Durability

One area of consideration of the design engineer in providing optimum durability is to insure the incorporation of maintainability in the design of the system. Analyses and tradeoffs must be made to determine the types and degree of maintainability and support required. All combinations of maintainability design features, together with the cost and associated repair times, must be considered in order to find the combinations that best meet materiel maintainability requirements. Restricted accessibility of modules, assemblies, and other items will contribute to the extension of repair time and, in worst case, require depot overhaul or rebuild to extend the useful service life. In this connection, it is a responsibility of both the design engineer and the maintainability engineer to pay close attention to the physical limitations of technicians, as well as the predicted failure rates of the several components that are subject to malfunction. It is important that every consideration be given, whenever economically and physically possible, to provide for easy access to parts with higher failure rates. System durability may be reduced if nonfailed parts must be removed and replaced during the maintenance of high failure rate items.

Another factor that should be considered when designing for durability is planned obsolescence. In this case, the durability of a component has to be designed to fit into the design durability of the system. Some types of planned obsolescence are widely accepted. Disposable dishes, containers, and clothing are common examples of planned obsolescence. The use of onetime devices in military and industrial operations can be the basis for achieving a high degree of performance reliability. Properly used, planned obsolescence favorably impacts manufacturing, material and maintenance costs, and materiel durability.

The weapon systems of today often require high performance components in order to increase the service life or durability of the system. In almost all cases, the term "high performance" implies that there is a high output per unit mass, a high payload per unit weight, a high attained speed, or high efficiency. Also implied is that the component is relatively heavily stressed. Since there is a direct relation between the degree of stress on the component and the relative lifetime, it generally will be true that high performance components tend to be short lived. This dictates that high-performance component applications be analyzed carefully and evaluated by the design and maintainability engineers to assess component reliability and maintainability, and insure system durability.

Many examples of design considerations have improved the reliability, maintainability, and durability of components and systems. The development of the surface-gap spark plug is a classic example. The service life of the plug itself was extended greatly once the erosion characteristics of the air-gap plug were eliminated. The excess carbon buildup of the air-gap plug caused reduced firing current and failures to fire that were detrimental to system (engine) performance and often resulted in catastrophic failure. This adversely affected durability, since overhaul or replacement was required prior to the projected service life or overhaul point of the system. The improved characteristics of the surface-gap plug have improved system reliability, maintainability, and durability.

Improvements in the design and production of generator brushes have improved the maintainability and durability of electrical devices. The development of hardened material compounds for electrical brush applications has not only increased the life of the brushes but reduced the possibility of system failures caused by the excessive carbon dust inherent to the soft brushes. The use of "bayonet-type" brush holders wherever possible has permitted the replacement of brushes from outside the housing without the need for removing or replacing covers. This has improved maintainability by allowing for rapid replacement and easy access for periodic cleaning and lubrication. All of these actions contribute to extending the service life, prevent premature or catastrophic failure, and thus increased durability.

Catastrophic and random failures have a dramatic effect on system durability. In order to assess properly system durability, the potential effects of catastrophic and random failures should be investigated carefully. If the failure is such that resultant corrective action requires system replacement or overhaul, durability will be decreased. These failures cannot be prevented, although the rates at which they occur are related to the environmental stresses to which the components are subjected. Although a finite probability of catastrophic failure always will remain, a decrease in the uncertainties in the manufacturing process by control of both materials and manufacturing techniques will reduce the failure rate and increase durability.

To provide optimum reliability and minimum maintenance, it is essential that components be balanced as to their fatigue life, with performance levels designed to achieve a logistically cost-effective life expectancy. The designer must consider preproduction testing and engineering data before he can select the components that will provide a system design with optimum durability.

The adequacy of system design should be determined by extensive age and deterioration testing, with sufficient test hours on as large a sample of prototype systems as economically feasible, in order to establish maintainability and service life factors. Establishing a quantitative relationship between maintainability and service life will contribute to the determination of more efficient maintenance practices and also provide the designer with fatigue and wear factors that influence life of components and, ultimately, the durability of the system.

3-4.10 REDUNDANCY ARRANGEMENTS

Redundancy exists when more of anything is provided than is necessary. It can exist in materiel in the form of extra strength, extra circuits, extra end items, etc. Normally, redundancy is considered to improve materiel reliability, but it can result in reduced reliability and frequently increases maintenance requirements. Maintenance engineering must understand what redundancy is, thoroughly understand its impact on system operation, and be well aware of the maintenance price that may be paid for any operational advantages.

Redundancy has different connotations for each engineering specialist—for example, to the structural engineer, a factor of safety; to the electrical engineer, a generator with the capacity to handle an overload without damage; to the lubricating engineer, a lubricating supply of more than normal requirements to take care of unforeseen eventualities; and to the reliability engineer, the capacity of a system to experience failure of hardware items without causing system failure. This discussion will limit itself to the reliability and maintenance aspects of redundant assemblies, components, etc.

A state of redundancy exists between two or more devices in parallel if one or more of the devices can fail without causing system failure, but at least one of the devices must succeed for the system to succeed. Either simple or compound redundancy may exist, depending upon the requirements for the successful operation of the parallel devices. Additionally, active or standby redundancy can exist within the simple and compound categories.

3-4.10.1 Simple Redundancy (Ref. 2)[2]

If n devices are in parallel so that only one of the devices must succeed for the system to succeed, then the devices are said to be in simple redundancy. To illustrate this concept, the diagram or model of a two-part redundancy system is shown in Fig. 3-6.

In other words, if part 1 fails, the system can still succeed if part 2 does not fail, and vice versa. However, if both parts fail, the system fails.

From probability Theorem 3 (par. 3-3.1.2), it is known that the possible combinations of success R and failure Q of two devices are given by Eq. 3-9.

$$\text{possible events} = R_1R_2 + R_1Q_2 + Q_1R_2 + Q_1Q_2 \qquad (3\text{-}9)$$

[2] *Ibid.*

where

R_1R_2 = both parts succeed

R_1Q_2 = part 1 succeeds and part 2 fails

Q_1R_2 = part 1 fails and part 2 succeeds

Q_1Q_2 = both parts fail.

It is also known that the sum of these events equals unity, since they are mutually exclusive; i.e., if one event occurs the others cannot occur.

So

$$R_1R_2 + R_1Q_2 + Q_1R_2 + Q_1Q_2 = 1. \qquad (3\text{-}10)$$

Since at least one of the parts or devices is expected to succeed in simple redundancy, the probability of this happening is given by

$$R_1R_2 + R_1Q_2 + Q_1R_2 = 1 - Q_1Q_2. \qquad (3\text{-}11)$$

In simple terms: if the only way the redundant system can fail is by all redundant parts failing, then the probability of success must be equal to 1 minus the probability that all redundant parts will fail; i.e., $R = 1 - Q$ from probability Theorem 1 (par. 3-3.1.2).

This reasoning can be extended to n redundant parts if at least one of the n parts must succeed for the system to succeed.

Example: Suppose there are three ways that a space capsule can be guided: automatically, with $R_1 = 0.9$; semiautomatically, with $R_2 = 0.8$; manually, with $R_3 = 0.7$. The model or diagram of successful guiding, assuming that the three ways are independent of each other, is shown in Fig. 3-7.

From probability Theorem 3 (par. 3-3.1.2), the possible events are given by Eq. 3-12.

$$R_1R_2R_3 + R_1R_2Q_3 + R_1Q_2R_3 + Q_1R_2R_3 + R_1Q_2Q_3 + Q_1Q_2R_3 + Q_1R_2Q_3 + Q_1Q_2Q_3 \qquad (3\text{-}12)$$

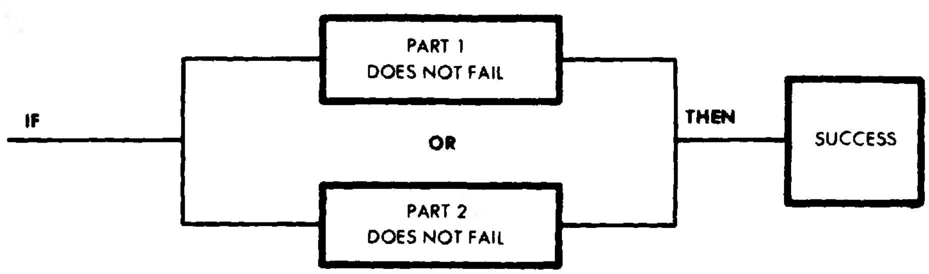


Figure 3-6. Simple Redundancy Model

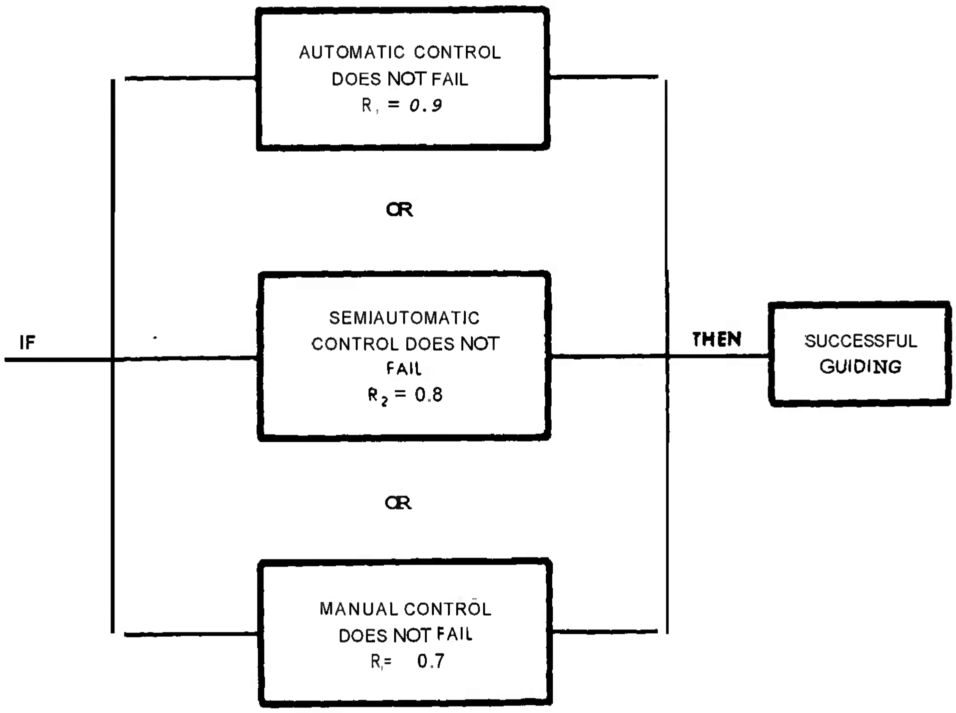


Figure 3-7. Space Capsule Guidance Model

Since the sum of these probabilities is equal to unity, and since at least one of the control systems must operate successfully, then the probability R_{Guid} that guidance will be successful, is

$$\begin{aligned} R_{Guid} &= R_1R_2R_3 + R_1R_2Q_3 + R_1Q_2Q_3 \\ &\quad + Q_1R_2R_3 + R_1Q_2Q_3 \\ &\quad + Q_1Q_2R_3 + Q_1R_2Q_3 \\ &= 1 - Q_1Q_2Q_3 \qquad (3\text{-}13) \\ &= 1 - [(1 - R_1)(1 - R_2)(1 - R_3)] \\ &= 1 - [(1 - 0.9)(1 - 0.8)(1 - 0.7)] \\ &= 1 - [(0.1)(0.2)(0.3)] \\ &= 1 - (0.006) \\ &= 0.994. \end{aligned}$$

In general, then, it can be stated that for simple redundancy

$$\begin{aligned} R_{Redundant} &= 1 - \prod_{i=1}^{n} Q_i \\ &= 1 - [Q_1Q_2Q_3 \cdots Q_n] \end{aligned}$$

where

$\prod_{i=1}^{n} Q_i$ = total probability of failure

Q_i = probability of failure of the ith redundant part

n = total number of redundant parts

3-4.10.2 Compound Redundancy (Ref. 2)

Compound redundancy exists when more than one of n redundant parts must succeed for the system to succeed. This can be shown in a model of a three-element redundant system in which at least two of the elements must succeed, as shown in Fig. 3-8.

From probability Theorem 3 (par. 3-3.1.2), the possible events are

$$\begin{aligned} &R_1R_2R_3 + R_1R_2Q_3 + R_1Q_2R_3 \\ &+ Q_1R_2R_3 + R_1Q_2Q_3 + Q_1Q_2R_3 \\ &+ Q_1R_2Q_3 + Q_1Q_2Q_3 \end{aligned}$$

as indicated by Eq. 3-12.

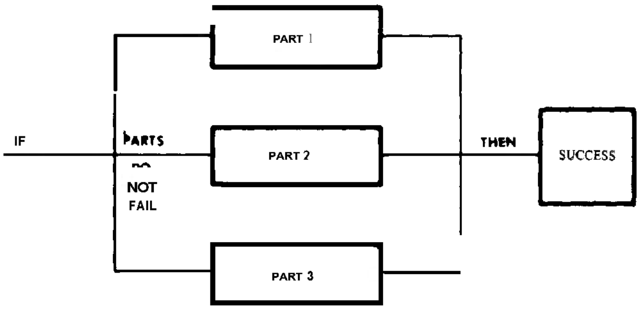


Figure 3-8. Compound Redundancy Model

To simplify the notation, let R_1 = R, = R, and $Q_1 = Q_2 =$ Q3. This reduces the preceding expression to

$$\left.\begin{aligned} &R^3 + R^2Q + R^2Q + R^2Q \\ &+ RQ^2 + RQ^2 + RQ^2 + Q^3 \end{aligned}\right\} \quad (3\text{-}14)$$

or

$$R3 + 3R^2Q + 3RQ^2 + Q^3$$

Since the sum of these probabilities equals unity, and at least two of the three parts must succeed, then the probability for success is given by

$$\left.\begin{aligned} R_s &= R^3 + 3R^2Q \\ &= 1 - [3RQ^2 + Q^3] \end{aligned}\right\} \quad (3\text{-}15)$$

since $3RQ^2$ represents one part succeeding and two parts failing, and Q^3 represents all three parts failing. •

Example: Assume that there are four identical power supplies in a fire control center and at least two of them must continue operating for the system to be successful. Let each supply have the same reliability, R = 0.9 (which could represent $e^{-\lambda t}$ or R_i or R). Find the probability of system success R,.

The number of possible events is given by

$$(R + Q)^4 = R^4 + 4R^3Q + 6R^2Q^2 + 4RQ^3 + Q? \quad (3\text{-}16)$$

The sum of the probabilities of these events equals unity, so the expression for two out of four succeeding is

$$\left.\begin{aligned} R_s &= R^4 + 4R^3Q + 6R^2Q^2 \\ &= 1 - [4RQ^3 + Q^4]. \end{aligned}\right\} \quad (3\text{-}17)$$

Substituting R = 0.9 and Q = 1 − 0.9 yields

$$\begin{aligned} R_s &= 1 - [4RQ^3 + Q^4] \\ &= 1 - [4(0.9)(0.1)^3 + (0.1)^4] \\ &= 1 - [(3.6)(0.001) + 0.0001] \\ &= 1 - [0.0036 + 0.00011 \\ &= 1 - 0.0037 \\ &= 0.9963 \end{aligned}$$

3-4.10.3 Active and Standby Redundancy

The devices in parallel comprising either a state of simple or compound redundancy may all be active at all times, or the active devices at any time may be limited to those mandatory for system success. The first arrangement is called active redundancy and the second, standby redundancy.

As an example of active redundancy in a system with simple redundancy, suppose that the model shown in Fig. 3-6 represents a system power source composed of two identical generator sets, either of which is capable of supplying total system power requirements. If active redundancy is practiced, both generator sets will be operating, one on line and the other off line. Sensing circuits will monitor the output of the on-line set and switch the load to the off-line unit if the system primary power levels drop below a predetermined level. The off-line generator is often referred to as the standby generator, but represents active redundancy since it is operating and experiencing stresses associated with rotating machinery. The power supply example in the discussion of compound redundancy is an application of total active redundancy. Here, all four power supplies are implied to be on line at all times. As supplies fail, the remaining supplies share the added load.

For either of the foregoing active redundancy examples, maintenance engineering should consider a true standby arrangement, provided such an arrangement will satisfy operational requirements. In the case of the generator example, the off-line generator set could be completely shut down, and started manually when the on-line set fails. Maintenance requirements will be reduced because of lower generator run times and, consequently, because of fewer failures and servicing requirements. Economies also can be realized from reduced fuel consumption. Except for fuel economies, an analogous discussion applies to the power supply example.

34.10.4 Redundancy, Reliability, and Trade-offs

The compound redundancy model (Fig. **3-8)** points out that more than one of n redundant parts must succeed for the system to succeed. Such a requirement actually can reduce system reliability. When more than one redundant device must succeed, the use of more than one device is often a result of incorporating off-the-shelf hardware to reduce initial acquisition costs. In new design, it also can result from standardization goals, whereby units such as standard power supplies are used "building block" fashion, and a pair of these supplies is used in parallel when the load demands exceed that of a single unit. Maintenance engineering must trade off the resultant reliability/availability impact of compound redundant units against the advantages of a single higher reliability unit with adequate capacity for the task. Increased initial acquisition costs for a new-design single unit may be offset by lower life cycle support costs, along with overall system availability.

A twin-engine aircraft illustrates the paradoxical manner in which a fixed hardware arrangement can be considered either redundant or nonredundant, by virtue of the operational mode under consideration. During a flight (assuming adequate single-engine performance for mission completion), the reliability of two engines exceeds that of a single engine since each engine is statistically an independent unit and simple redundancy exists. The single-engine aircraft, given an engine type the same as that of the other aircraft, has a higher probability of complete power loss (and termination of the mission) over the same number of flight hours.

A different situation exists at the start of a mission. No twin-engine aircraft, military or civil, will start a flight without both power plants operating normally. A zero redundancy condition then exists because both of the formerly redundant units must be operating properly. As for the probability of operation, if the probability of one engine operating is R, the probability of two engines operating is R^2. The twin engines not only reduce aircraft availability, but engine maintenance is doubled, which adversely impacts requirements for personnel, repair parts, etc. If it is assumed that the power of two of the engines being discussed is an operational requirement, maintenance engineering should trade off the costs of a single, more powerful engine and its support versus similar costs for two of the smaller engines per aircraft.

A requirement exists for trade-offs between mission requirements and potential added maintenance costs whenever redundancy is considered. The lower maintenance and initial acquisition cost of a single-engine aircraft must be traded off against mission requirements, probability of failure, and the system impact if failure occurs. Similar trade-offs are required when considering dual generators, power supplies, transmitters, backup guidance systems, backup relays, and other redundant hardware. Mission essentiality always must be considered in evaluating alternatives. If a police radar unit is down because its single power supply fails, it is a source of aggravation to the police, but no real harm is done. On the other hand, the failure of a ground control radar, due to a lack of backup power, can have disastrous results for an aircraft under control during certain weather and terrain conditions.

Once trade-offs have been conducted and an approach selected, maintenance engineering continually must monitor the design to insure that the advantages of the selected approach are not compromised. For example, a simple-redundancy, standby arrangement was chosen for the generators in some ground support equipment. When one generator was running, the other was off, and the arrangement met system availability requirements. The maintenance concept was such that maintenance could be performed on the passive unit while the other was operating. This quite logical approach was scuttled when a design decision was made to mount the units in such a way that work on the passive unit was impossible because of the safety hazard presented by the proximity of the operating unit. Additional maintenance engineering influence corrected the situtation, but this type of incident emphasizes the need for continual monitoring of design activity by the maintenance engineer. The monitoring task is all inclusive and continuous, beginning with quantitative design and redundancy requirements at the system level and encompassing all levels of design, down to paralleling of piece part hardware.

3-4.10.5 Examples of Redundancy in Materiel (Ref. 1)

Some examples of redundancy in various types of materiel are:

a. Dual electrical power supply, each capable of fulfilling the product mission

b. Electrical plugs on outside of product, to supply product with power normally generated on board

c. Dual or multiple prime movers, each, or in combination, capable of sustaining satisfactory motion

d. Front and rear drives on land vehicles separately driven from prime mover, each capable of continuing their function in the event the other fails

e. Multiple braking systems, each capable of operation should the other fail

f. Hand crank on engines with self-starters, to crank engine in the event self-starter fails

g. Auxiliary power plants, to substitute for main power source

h. Multiple sealed compartments in floats, boat hulls, etc., each, or in combination, capable of sustaining flotation

i. Dual control systems, either of which will serve the intended mission or function. Typical are:

(1) Two identical controls

(2) Power plus mechanical activation

(3) Dual cable, wire, or push rod

j. Dual electrical or electronic circuits, each able to substitute for the other

k. Dual vehicle tires on one axle, each capable of carrying the load in case the other fails

l. Multiple fuel tanks, each capable of being valved to serve all engines or a combination thereof

m. Dual fuel systems, each capable of supplying an engine in the event the other fails

n. Tire tube inside an outer tire tube, to carry the load and fulfill the mission in the event the outer tube fails

o. Two or more fasteners, each, or in combination, capable of carrying the load in the event the other fails

p. Multiple fuzes on ordnance items, to further assure satisfactory action in the event the others malfunction or fail

q. Local manual fire control, to substitute for automatic fire control on military items (guns, missiles, etc.)

r. Telescopic rangefinders, to substitute for radar rangefinders

s. Multiple bilge pumps, each having its own sources of energy, and capable of performing the function of the other

t. Visual or audible warning system, to operate simultaneously with, for example, an automatic fire extinguishing system

u. Multiple fire extinguishing systems, each capable of being directed into the other's normal area

v. Multiple escape means, to afford quick exit from a single compartment in an emergency

w. Two or more methods for shutting down a device, in the event the normal method fails

x. Military fire control systems for a single weapon or battery, capable of alternate use with gun or missile without delay

y. Alternate air intake source to carburetors, to prevent or correct icing or contamination

z. Oil tanks of sufficient size to permit continued satisfactory lubrication even though a small leak or seepage exists

aa. Resettable circuit breakers, capable of immediate reuse, and without having to replace a less complicated item such as a fuse *ab.* Test or calibration equipment with universal capability; for example:

(1) Multifunction meters capable of reading volts, ohms, amperes, and watts

(2) Universal missile checkout device capable also of serving more than one type of missile

ac. Dual means of communication, such as a telephone intercommunication system, horn, bell, light, etc.

ad. Frequency change equipment in a radio transmitter or receiver, to permit two or more radios normally used on two or more channels to be substituted for each other

ae. Stiffened fuselage bellies, capable of reasonably resisting forced belly landings in the event of landing gear failures

af. Manual overrides on power-actuated components, such as on retractable aircraft landing gears, power-driven hatches, flight controls, ship steerage, etc.

3-5 MAINTENANCE ENGINEERING INFLUENCE ON MAINTAINABILITY ASPECTS DURING DESIGN

Maintainability is a characteristic of design and installation which is expressed as the probability that an item will be retained in or restored to a specified condition within a given period of time, when the maintenance is performed in accordance with prescribed procedures and resources.

During materiel design, maintenance engineering continually conducts analyses and trade-offs to insure that optimum maintainability is incorporated into design. The identification of trade-off candidates is based on historical data, experience, and judgment. All candidates must satisfy operational requirements, and this fact is implicit in the remainder of this discussion. The purpose of the trade-offs is to select design features that will reduce life cycle support costs more than they increase acquisition costs.

Maintenance engineering maintains current knowledge of the status of materiel design through program documentation, personal contact with engineers, review of mock-ups, models, and prototype hardware, and design reviews. Maintainability design reviews provide an excellent source of information since they are devoted exclusively to the review of design features in which maintenance engineering has great interest. In evaluating design at such reviews, maintenance engineering draws heavily on historical data and experience.

In evaluating a design either from a drawing or at a design review, maintenance engineering is interested in establishing or improving design features that reduce support costs and simplify and reduce maintenance. There is a multitude of such design features. A few of the most important are discussed in the paragraphs that follow.

Support costs can be reduced by standardization. The single most important standardization requirement, and it is normally not considered standardization, is to design materiel so that it can be supported within the existing logistic system. Any other design will generate a host of expenses and problems. One of the actions required to attain the overall standardization goal is to design materiel so that standard test equipment, repair parts, and fasteners can be used. An additional design requirement is to keep the number of different types of these items to a minimum. Support costs also can be reduced by reducing the required quantity of repair parts, whether standard or nonstandard, and by simplifying and reducing maintenance.

The ultimate way to simplify and reduce maintenance is to eliminate it. Maintenance engineering should insure that maintenance-free components and assemblies are incorporated into design whenever this is cost-effective. Maintenance simplification without reducing maintenance frequency can be attained by designing materiel for maximum accessibility and for ease of maintenance. The need for accessibility applies to both corrective and preventive maintenance.

Simplification of maintenance also can be attained with a design that is oriented toward optimum organizational maintenance requirements. Such a design almost always incorporates modular features. When discard-at-failure modules are used, maintenance is not only simplified, but reduced.

Maintenance reduction without simplification can be achieved through design. An example of this is the design of a circuit with self-protective features. Such features can preclude both operating damage, as from voltage surges, and maintenance damage. A second example is to select and install wires and cables properly that will not fail as a result of natural and induced environments.

3-5.1 TRADE-OFF PARAMETERS

Trade-off analysis is the process of analyzing and evaluating possible alternative solutions to a problem and then choosing the solution that best satisfies the explicit and implicit constraints. Explicit constraints are operational parameters such as speed, weight, accuracy, and availability. Implicit constraints may be tangible, such as state of the art limitations, or intangible, such as user acceptance of a new concept.

The reason for trade-off studies is to reach optimum design versus support decisions. Optimization can be attained only by considering all facets of a problem. Alternatives that are patently unacceptable should be identified but not treated in depth during the trade-off analysis study period. It is emphasized, however, that the validity of trade-off decisions depends on the completeness and thoroughness of the study. Tentative relationships, if properly developed, are frequently useful for making gross comparisons of alternatives. Care must be exercised not to use relationships that are overly sensitive to the parameters being varied.

Trade-offs during early materiel program phases involve operational, maintenance, and support parameters. All parameters are loosely bounded in such trade-offs. Consider a guided missile system. Large payloads in economical, relatively inaccurate missiles might prove to be more cost-effective than small payloads in highly sophisticated missiles. Similarly, large numbers of missiles of relatively low reliability might be more cost effective than the required numbers of highly reliable missiles. Maintenance concepts might range from discarding a missile at failure to complete repair. All logical design and support combinations that show promise of satisfying operational requirements are traded off, and a basic design and a support approach are selected.

Operational parameters become relatively firm after the foregoing trade-offs, as does the basic hardware design. Subsequent trade-offs are largely between maintenance and support parameters to determine how established operational requirements can be satisfied most economically. The operational parameter of availability comprises a prime trade-off area. Numerous combinations of reliability and maintainability will provide a specified availability, and each combination impacts virtually all support parameters and acquisition and life cycle costs. During these trade-offs, materiel repair levels, maintenance locations, and test and packaging concepts are established.

A final series of trade-offs involves the verification, refinement, and definition of previously established maintenance and support parameter concepts. For example, automatic test equipment could be a maintenance parameter concept. It is now determined whether or not this should be built-in test equipment.

To make final determinations regarding maintenance and support parameters, it is necessary to consider test levels and packaging concurrently and examine the impact on support parameters at all maintenance levels. All logical maintenance parameters are traded off. Any design feature that will eliminate, reduce, or simplify maintenance is examined in detail for its impact on the support parameters and life cycle costs. Finally, support concepts are traded off. Such trade-offs might not affect maintenance parameters, but can heavily impact support parameters. For example, a trade-off between field maintenance and aepot maintenance will affect, at a minimum, requirements for personnel, training, support equipment, facilities, and transportation.

All maintenance and support parameter trade-offs are important, but possibly the most important decisions applicable to all types of materiel that must be established by trade-offs concern:

a. Modularization

b. Repair level

c. Fault isolation

d. Maintenance concept

e. Maintenance complexity

f. Reliability

g. Adjustments

h. Calibration

i. Accessibility

j. Standardization

k. Interchangeability

l. Logistic requirements.

3-5.2 MAINTAINABILITY DESIGN REVIEWS

Design reviews of a materiel development program are conducted at critical points during the development cycle. The purpose of the reviews is to evaluate the status of the program, accomplish effective coordination, and facilitate timely management decisions. These reviews provide an efficient method for maintainability and maintenance engineering personnel to see what has been accomplished and what remains to be accomplished in the area of maintainability. Concurrently, maintenance engineering makes similar determinations pertaining to closely allied disciplines such as reliability, human factors, and safety.

Initially, design reviews deal with concepts. As the materiel program evolves, concepts become specifications and specifications lead to hardware. In general, design reviews are conducted at each transition point. The major purpose of the conceptual review is to assure that the selected design concept will satisfy maintainability requirements and will be cost-effective. Quantitative data on which to base decisions are limited.

At the time that specifications become available, initial materiel design is nearly complete and some components and assemblies will have undergone some development testing. The capability of materiel design to satisfy maintainability requirements is evaluated by making a formal maintainability prediction. In the event of deficiencies, design recommendations are made. This is the last chance to influence design with relative economy. Subsequent changes will impact hardware rather than drawings.

After hardware becomes available and some test data are generated, maintainability deficiencies may be identified with relative ease, both before and during design reviews. Once again, design recommendations to correct deficiencies are submitted. The recommendations pertaining to deficiencies that keep materiel from satisfying operational requirements (design specifications) normally receive approval. Other recommendations normally will be disapproved unless they can be effected with minimum cost impact, or demonstrate an overwhelming savings in support resources.

It is quite difficult to insure, through conceptual and specification reviews, that full and adequate provisions have been made for maintainability. This is mainly because there is such a variety of requirements to be considered, and it is difficult to visualize the hardware configuration that will eventually emerge. It is relatively easy to determine deficiencies in hardware but, as has been pointed out, it is difficult to get design changes accepted at this time. To make complete, timely maintainability recommendations, maintainability checklists are prepared and used.

A properly prepared maintainability checklist should encompass basic maintainability principles, as well as specific parameters applicable to the class of materiel being reviewed. It can be prepared most efficiently by starting with checklists that have been used during maintainability design reviews of similar materiel (including hardware reviews), and resulting maintainability reports. This should be augmented with field data, when available. Such documentation will highlight potential problem areas, and may permit discovery of deficiencies in the design stage that otherwise would have been undiscovered until hardware was fabricated.

Besides operational hardware, maintenance engineering has a design review interest in the planning and progress associated with the definition and acquisition of support resources. It is necessary to insure that adequate support equipment, trained personnel, documentation, repair parts, etc., will be available when required. This effort also requires a checklist and, as before, preparation of the checklist best can be accomplished by using previous design review documentation and field usage data as source information.

3-5.3 DESIGN ORIENTED TO ORGANIZATIONAL MAINTENANCE LEVELS

Materiel design and its optimum maintenance concept are interdependent. Repair level, repair location, modularization, fault isolation, and similar decisions must be made concurrently as a result of comprehensive cost-effectiveness trade-offs. Normally, such trade-offs will demonstrate the desirability of keeping maintenance functions at the organizational level simple and capable of rapid performance. This situation results from a combination of operational requirements and life cycle costs.

The operational requirement that establishes the maximum and average times available for corrective and preventive maintenance is availability. Usually, these times are of relatively short duration, and a rapid repair capability becomes necessary to satisfy the requirement.

Once operational requirements are satisfied, additional simplification or time decreases in organizational maintenance must be justified on the basis of cost effectiveness. The Army-wide cost benefits accruing from such design changes are reduced requirements for personnel skills and numbers, support equipment, and facilities. Equally important, simple and quick organizational repairs are more likely to be reliable than complex and lengthy ones.

The simplification of organizational maintenance can be accomplished in a variety of ways, and each will have a unique impact on total support resource requirements. Three greatly simplified examples will demonstrate this statement. If organizational maintenance is simplified through improved mechanical and electrical packaging and accessibility, organizational personnel can perform more work in less time, and the maintenance load and resource requirements normally will decrease at the other levels. This is true because the organization is performing some maintenance that previously was performed by higher maintenance levels. Acquisition costs of the prime materiel normally will increase insignificantly.

If organizational maintenance is simplified through improved mechanical and electrical packaging and accessibility and built-in test equipment, organizational maintenance personnel can perform more work in less time, but added maintenance resources (personnel, support equipment, and repair parts) will be required somewhere in the support subsystem to support the added test equipment. Additionally, acquisition costs of the prime materiel normally will increase.

The foregoing examples assume repairable modules. If a concept of discarding modules at failure is added to the second example, the organizational maintenance workload will not change, the maintenance workload at higher maintenance levels will decrease, and repair part costs normally will increase, since repair is effected by replacing and discarding a module comprising multiple parts rather than by replacing and discarding a single part. The repair part costs normally will be offset to some degree by improved reliability and reduced manufacturing costs that may be realized by using discard-at-failure rather than repairable modules. Compared to the second example, acquisition costs of the prime materiel will not be affected significantly.

In addition to the cost factors identified for the three design and maintenance approaches, each approach will generate unique technical data, training, transportation, support equipment, and, perhaps, facility costs. The only way to select the most cost-effective materiel design and support subsystem combination is to conduct cost trade-offs.

3-5.4 SYSTEM COMPATIBILITY

The Army logistic system consists, in part, of the concepts, management and control systems, and resources required to acquire and maintain materiel and facilities (see par. 3-4). Any facet of a new materiel program that requires a modification of the logistic system is a potential source of unnecessary trouble and costs. This does not mean that it is always undesirable to effect a change. No changes result in no improvements. However, when feasible, new materiel should be designed to be acquired and supported within the existing logistic system. Exceptions to this principle are acceptable only when dictated by state-of-the-art considerations, or where cost savings and improved effectiveness can be demonstrated.

Materiel not compatible with the logistic system is most apt to impact the logistic elements of movement, maintenance, and facilities. For movement, the logistic system envisions the use of existing and planned military and commercial vehicles to move materiel by highway, rail, airplane, and ship. Materiel that cannot be moved by standard vehicles in all transportation modes inhibits the flexibility of the Army to move equipment rapidly and economically from point to point. Materiel size and fragility are two factors to consider. Size can limit transportation to a small percentage of existing vehicles, or can result in a requirement for new vehicles. Shock and vibration limitations can preclude the use of rail and sea transportation, and require expensive packaging to protect items when moved by other transportation modes. Materiel sensitive to non-nuclear radiation generates a requirement for route surveys and restricts permissible routing. Temperature limitations can generate a host of transportation problems.

The maintenance element of the logistic system is particularly sensitive to new requirements for personnel skills, support equipment, lines of repair parts, and equipment publications. New skill requirements can trigger new recruiting requirements, and always result in new training courses and all of the attendant student and school expenses.

New support equipment requirements generate new personnel and training requirements, and provisioning and supply management expenses. New lines of repair parts also generate provisioning and supply management expenses. Both support equipment and repair parts eventually impact the previously discussed logistic element of movement. All maintenance-associated requirements discussed so far impact equipment publication requirements.

Maintenance and storage facilities are associated closely with maintenance. New mobile and temporary facilities perturb the logistic system to a limited degree, but permanent facilities such as depots and fixed general support unit shops have deep implications. This is partly because of the structures, but mainly because of the personnel and support equipment associated with a fixed facility operation.

The impact of new logistic requirements on the logistic system is somewhat proportional to the degree by which the new requirement exceeds the existing capability, as long as the existing capability can be appropriately modified. If an absolutely new capability is required, the impact can become extremely significant. An example of this is a requirement for a new skill. If the new skill can be attained by retraining an existing skill, and if there is a sufficient number of the existing skills, the problem can be solved with the expenditure of training resources. On the other hand, if skill requirements exceed the skill inventory and retraining is not feasible, there is a problem that will require extraordinary effort in effecting a solution.

3-5.5 REPAIR PARTS STANDARDIZATION (Ref. 1)

Repair parts standardization is an effort to effect optimum interchangeability of repair parts and components, and thereby reduce supply management and procurement costs. It is an intra-Army as well as an interservice activity. When standardization is carried out to a maximum degree, it results in substantial cost savings, has favorable reliability implications, and usually assists in making materiel more maintainable. It should be noted that the standardization of materiel end items is the most effective way of standardizing repair parts and components.

The primary goals of a standardization program are to:

a. Reduce the number of different models and types of equipment in use.

b. Maximize the use of common parts in different equipment.

c. Minimize the number of different types of parts, assemblies, etc., and attendant supply problems and make maximum use of standard, interchangeable items.

d. Use only a few basic types and varieties of parts, assemblies, etc., and ensure that those parts are readily distinguishable, compatible with existing practices, and used consistently for given applications.

Maintenance engineering assists in the attainment of these goals by reviewing design and, later, materiel to insure that standardization principles are being followed. Some typical requirements are:

a. Make all items subject to removal and replacement standard and uniform.

b. Use standard available parts rather than those of special manufacture.

c. Avoid parts made by only one manufacturer, when feasible.

d. Insure that all parts having the same manufacturer's part number are directly and completely interchangeable with regard to form, fit, and function.

e. Insure that like assemblies, components, etc., are directly and completely interchangeable when they are procured from multiple sources.

Standardization results in a wide range of advantages, whose aggregate results in improved cost-effectiveness. Specifically, standardization will:

a. Avoid requirements for special tools, etc.

b. Save design time, manufacturing cost, and maintenance time and cost.

c. Result in more uniform and predictable reliability.

d. Minimize the danger of misapplication of parts, assemblies, etc.

e. Prevent accidents that arise from improper or confused procedures.

f. Facilitate "cannibalizing" maintenance procedures.

g. Reduce errors in wiring, installation, replacement, etc., due to variations in characteristics of similar equipments.

h. Reduce supply management costs.

i. Reduce materiel modification costs.

j. Reduce the number of line items that must be stocked at all maintenance levels.

In spite of the many benefits that accrue from standardization, efforts in this direction must be guided by prudent judgment. Frequently, improved performance requirements for materiel preclude the application of standard parts. In such cases, it should be established unequivocally early in a materiel program that the advantages of improved performance outweigh the advantages of standardization. Once this is an established fact, maintenance engineering should not fight the problem, and should devote standardization attention only to the viable candidates in the program, such as multiple usage of the nonstandard parts.

3-5.6 REDUCE LEVEL OF TECHNICAL SKILLS REQUIRED (Ref. 1)

The level of organizational technical skills required to perform materiel maintenance always can be reduced by the use of modular construction. The level of skills required at all maintenance levels can be reduced if the modules are discarded at failure; otherwise, a higher maintenance skill is required at some level to effect the repairs not accomplished by the organizational level. There is a tendency to think of modular construction as being almost exclusively associated with electronic equipment, but this is an incorrect concept. Normally, electronic equipment can be modularized to a greater degree than mechanical equipment, but the fundamental benefits of modularization apply equally to all materiel types.

Advances in microelectronic engineering make it possible to package many circuits (functions) into extremely small volumes. These integrated circuits have low power requirements and exceptionally high reliabilities. Their initial cost is competitive with the cast of similar circuits that have discrete, solid-state components. Considering the reduced maintenance costs that result from improved reliability, integrated circuits cost less than discrete circuits on a life cycle basis. Assuming that they are not misapplied, most integrated circuits that do fail, do so as a result of manufacturing problems rather than wear-out. Manufacturing processes and production acceptance testing are improving continually. Packaged microelectronic circuits frequently are designed as discard-at-failure modules. Due to their high reliability, redundant modules normally are not required to achieve required system availability. Conversely, the circuits make it economically and technically feasible to incorporate a self-repair capability into materiel by providing redundant circuits.

3-5.6.1 Modules

A module is a functional materiel entity that may be comprised of a complete materiel end item, or any portion thereof. In the event that it is a part of an end item, it must be capable of being economically removed, replaced, maintained if necessary, tested, transported, and handled. For example, a module may consist of a missile, a missile section, an electronic chassis, a printed wiring board, a tank engine, or a hydraulic pump. The degree to which the concept is applied depends on the particular application of the equipment, its practicality, and cost-effectiveness.

Modules can be designed to be fully repairable, partially repairable, or nonmaintainable. In a fully repairable design, all parts should have maximum life expectancy, be easily accessible, and capable of being removed without special tools. In a partially repairable design, the replaceable parts should be chosen so that their life expectancies are approximately equal, are removable and replaceable without special tools, and are readily accessible. A nonmaintainable design should have all parts designed for approximately equal life expectancies.

3-5.6.2 Advantages

The concept of modularization creates a divisible configuration to maintain. Troubleshooting and repair of modules, therefore, can be performed more rapidly. Utilization of this technique to the fullest extent improves accessibility, makes possible a high degree of standardization, provides a workable base for simplification, and provides the best approach to maintainability at all maintenance levels.

Modular construction offers particular advantages at the organizational level of maintenance. Because of the grouping of similar functions in a module, fault isolation is facilitated. Modules then can be removed and replaced with relatively low skill levels and minimum tools. This accomplishes a prime objective of maintainability—the reduction of downtime to a minimum. Defective modules can be discarded (if nonmaintainable), salvaged, or sent to a higher maintenance level for repair.

Other advantages of modules are that materiel modifications can be efficiently incorporated, and better utilization can he made of high skill levels and support equipment. Modifications can be incorporated by modifying modules at an optimum maintenance level, and shipping the modules to organizational activities for installation. High skill levels can be grouped with appropriate support equipment in a field level maintenance organization, or at the depot, and accomplish maintenance for a number of using organizations.

3-5.6.3 Design Considerations

In designing for modular construction, the following principles should be considered:

a. The materiel should be divided functionally into as many modular units as are electrically and mechanically practicable in keeping with efficient use of space and overall reliability.

b. An integrated approach should be used, considering simultaneously the problems of materials, component design, and application of the modular concept.

c. When feasible, modules and component parts should be approximately uniform in basic size and shape for the best packaging.

d. A modular unit should contain components that are optimized for a given function rather than providing multiple, divergent functions.

e. Modular units or subunits should be designed to permit testing when removed from the equipment and little or no calibration after replacement.

f. The physical separation of equipment into replaceable units should be matched with the functional design of the equipment. This will maximize functional independence of units and minimize interaction between units.

g. When an assembly can be made up of two or more subassemblies, the major assembly should be designed so that it consists of subassemblies that can be removed independently, without removal of the other subassemblies. This is especially valuable when the various subassemblies have widely varying life expectancies.

h. Design all materiel so that rapid and easy removal and replacement of malfunctioning components can be accomplished by one technician, unless it is structurally or functionally not feasible.

i. When possible, modules should be made small and light enough for one man to handle and carry. Handles should be provided on units that can be manhandled and weigh more than 10 lb, and easily accessible lifting points should be provided on modules that must be lifted mechanically.

j. When possible, each module should be capable of being checked independently. If adjustment is required, the module should be designed so that it can be adjusted separately from other units.

k. Control levers and linkages should be designed so that they can be disconnected easily from components to permit easy removal and replacement.

l. Modularization should be emphasized for forward levels of maintenance to enhance operational capability. Modularization versus parts replacement for shop and depot maintenance can be determined to a considerable extent by cost factors.

m. If all components of a module except one or two are reliable, the module should be designed so as to particularly facilitate the removal of the unreliable components from the module.

n. When possible, consistency should be observed in pin arrangements on electronic modules; i.e., input power pin, output signal pin, etc., in identical locations.

3-5.6.4 Disposable Module Considerations

A disposable module is a module designed to be discarded rather than repaired after it has experienced a validated failure. Since disposable modules are the only ones that result in elimination rather than transfer of maintenance to other levels, they are of extreme significance to maintenance engineering. In the past, it was quite difficult to convince management that it made economic sense to discard rather than repair a module costing several hundred dollars. Fortunately, this attitude is changing, but a maintenance engineering tradeoff that convinces all management levels that a relatively expensive module should be discarded rather than repaired at failure remains a challenging assignment. This is as it should be, because, once made, a decision to use disposable modules is extremely expensive and time consuming to reverse.

3-5.6.4.1 Advantages and Disadvantages

The most significant advantage of a disposable module is that it reduces maintenance personnel, support equipment, and resource requirements, and hence support costs. This advantage could be negated by the fact that, normally, the module can be designed for maintenance, and upon failure can be repaired by the replacement of a relatively inexpensive component. This requires the application of resources that were noted as savings under the disposable concept. The basic question is whether the life cycle costs for disposable modules are less than those for the maintainable modules. If the answer is positive, disposable modules should be selected.

Disposable modules have other advantages and disadvantages, but they would rarely influence a selection decision unless the two sets of costs previously discussed are almost identical. Table 3-10 lists both the primary and secondary advantages and disadvantages.

3-5.6.4.2 Design Requirements

Once a decision is made to discard modules at failure, they should be designed, manufactured, and installed to meet the following criteria to the greatest feasible extent:

a. Expensive parts are not discarded for failure of cheap parts.

b. Long-life parts are not thrown away for failure of short-life parts.

c. Low-cost and noncritical items are, in general, made disposable.

d. Disposable modules are encapsulated whenever practical.

e. All encapsulated modules are designed for disposal at failure.

f. The maintenance level of discard at failure is clearly specified.

g. Test procedures to be applied before disposal are clearly specified and provide clear and unequivocal results.

h. The identification plate or placarding is marked: DISPOSE AT FAILURE.

TABLE 3-10. ADVANTAGES AND DISADVANTAGES OF DISPOSABLE MODULES

Advantages	Disadvantages
1. Savings in repair time, tools, facilities, and manpower.	1. Module discarded for each validated failure results in increased repair part costs.
2. Smaller, lighter, denser, simpler, and more durable, and more reliable design.	2. Excessive usage rates through erroneous replacement.
3. Fewer types of repair parts and a one-way supply system, at least for the item.	3. Increased supply burdens because modules must always be on hand.
4. More concise and less difficult trouble-shooting procedures.	4. Reduction in failure and maintenance data to aid design improvement.
5. Use of sealing and potting techniques that further improve reliability.	5. Redesign problems and costs because such modules cannot be modified.
6. Improved standardization and interchangeability of 'modules and assemblies.	6. Degraded performance and/or reliability as a result of production efforts to keep modules economical enough to justify disposal.

3-5.7 STANDARDIZE FASTENER TYPES (Ref. 1)

Fasteners are available in a wide variety of types and sizes, and new types are constantly appearing. The inventory of required tools and fasteners, as well as the publication effort, is adversely affected by numerous, dissimilar fasteners. Maintenance engineering, therefore, establishes requirements to standardize fastener types and sizes, and monitors design to insure that the requirements are satisfied. Before establishing the requirements, fastener types and their application must be considered.

3-5.7.1 Types of Fasteners

Fasteners are used to join together two or more parts, components, or units. They include devices such as quick-release fasteners, latches and catches, captive fasteners, combination-head bolts and screws, regular screws, internal wrenching screws and bolts, and rivets. Each type has certain advantages for various applications. The following paragraphs contain some general recommendations and applications for each type of fastener in order of preference:

a. Quick-release Fasteners. Quick-release fasteners, also called cowl fasteners or panel fasteners, are fast and easy to use, do not always require tools, may be operated with one hand, and are very good for securing plug-in components, small components, and covers. However, their holding power is low and they cannot be used where a smooth surface is required. They should be evaluated carefully on the basis of type and application, and used, whenever possible, for components that' must be frequently dismantled or removed.

b. Latches, Catches, and Clamps. Latches and catches are very fast and easy to use, require no tools, have good holding power, and are especially good for large units, panels, covers, and cases. They cannot be used where a smooth surface is required. Latches and catches should be located and positioned so that accidental opening is minimized. Clamps of the quick-release type should be provided for holding wires, tubing, or hoses that must be removed frequently. Hinged clamps are preferable for mounting tubing or wiring on the face of a panel. Such clamps facilitate maintenance by supporting the weight of the line, thus freeing both hands for the required task.

c. Captive Fasteners. Captive fasteners, stay in place, save the time spent handling and looking for bolts and screws, and require only one-handed operation. They are somewhat slower and more difficult to use than the previously described fasteners. Captive fasteners should be used whenever lost screws, bolts, or nuts might cause excessive maintenance time, or could cause damage as a foreign object. Their use should be limited only to the type that can be operated by hand or common tools and can be replaced easily in case of damage. Self-locking, spring-loaded action should be provided on the quarter-turn type.

d. Screws. Because machine screws can be removed and replaced easily, they are used more than any other type of mechanical fasteners in some types of equipment. There are, however, more than **30** screw-head styles available. Eight head styles have been standardized by the American Standards Association, but military usage generally should be restricted to two styles, either the panhead or the flathead, according to whether or not a flush assembly is desired. Captive screws, which are becoming more and more common in field equipment, are particularly desirable for use on panels that require frequent removal. Captive screws cannot be detached easily from the panel, although they generally turn easily for removal of the panel. Also, they can be turned by hand and do not require a tool.

e. Nuts. Nuts can be divided into two general classifications: plain (or nonlocking) and locking, with a possible subclassification of fixed or nonfixed in each classification.

Self-locking nuts are intended to replace cotter pins, wiring, lockwashers, etc., as a means of keeping a nut tight on its bolt. They contain some means of gripping the threaded member so that relative rotation is impeded or prevented. This feature poses some problems if the nut is to be removed frequently during maintenance. Many specifications state that self-locking nuts should be capable of being removed from and replaced on the same threaded member at least 15 times, but most are removed and replaced far more often.

Fixed nuts are prefixed rigidly to the chassis by welding, riveting, clinching, or staking and are used where the metal is too thin or too soft to tap or where space is limited so that the nut would be inaccessible. They offer advantages in assembly and repair because bolts can be installed without handling the nuts, but they are subject to failure and should be designed to facilitate replacement. Trends toward modularization or unitization might increase the use of fixed nuts and reduce the variety of wrenches needed.

f. Bolts. Bolts are usually slow and difficult to use; they require two-handed operation, access to both ends of the bolt, and often the use of two tools. They also require precise movements in starting nuts and have many loose parts to handle and lose (nuts, washers, etc.).

g. Internal Wrenching Screws, Nuts, and Bolts. Internal wrenching fasteners allow higher torque, better tool grip, and less wrenching space. However, they are easily damaged, difficult to remove, and require special tools. The number of different sizes should be minimized to require as few special tools as possible. Slots should be deep to minimize damage to the fasteners. Otherwise, the requirements are similar to those for bolts and screws.

h. Rivets. Rivets should be used as fasteners only when they will not require removal or replacement. Although rivets are the most permanent type of fastener, they are not reusable and require greater time and effort for replacement than do screws or bolts. The use of wire stapling or metal stitching is generally preferable to rivets for maintenance purposes.

3-5.7.2 Standardization

Fastener standardization in materiel is made difficult by the fact that the optimum application of the same type fastener to several materiel locations can result in a different size for each location. This is the result of varying types and thicknesses of materials being fastened, varying mechanical stresses, etc. In some circumstances, it is cost-effective to overdesign, i.e., use a larger fastener than required, in order to limit sizes within a type. A reduction in the number of torque requirement values can be accomplished in a similar manner. Such decisions cannot be made without the benefit of trade-offs.

Standardization efforts should be governed by the following considerations:

a. Minimize the number of types and sizes of fasteners within the system:

(1) Use only a few basic types and sizes which can readily be distinguished from each other.

(2) Use the same type and size of fastener for a given application (for instance, all mounting bolts for a given type of item).

(3) Insure that screws, bolts, and units having different thread sizes are unmistakably different in physical sizes; otherwise, they may be interchanged.

(4) Avoid requirements for special or close-tolerance fasteners.

b. Minimize the number of differing torque requirements within the system:

(1) Use only a few basic values.

(2) Key these values to'clearly differing types, sizes, or coded fasteners.

(3) Plan for and provide clearance for wrenches or socket tools with variable torque settings when precise torquing is required.

c. Minimize the number of tool types and sizes required for fastener operation:

(1) Avoid requirements for special tools.

(2) Select fasteners for hand operation by common hand tools.

3-5.8 LIFE CYCLE REPAIR PART REQUIREMENT TRADE-OFF

, The three greatest contributors to materiel life cycle support costs are personnel, support equipment, and repair parts. Depending upon the type of materiel, repair part costs sometimes will rank in magnitude just behind those for personnel and sometimes behind those for support equipment. In either event, repair part costs on a major materiel program are always significant. These costs consist of initial stockage costs, which are nonrecurring, and supply management (par. 3-4.2) and repair part replenishment costs, which are recurring.

Life cycle repair part costs are dependent upon materiel design and the maintenance concept. More specifically, the costs are dependent upon the reliability of parts, the degree of modularization, and the determination of the repair and maintenance levels. All of these considerations, taken together, permit a determination of the range and depth of repair parts required in the initial buy and a prediction of replenishment requirements.

The interdependence of repair part requirements with design and the maintenance concept makes it virtually impossible to conduct a meaningful trade-off restricted to repair parts alone. For example, it is a foregone conclusion that disposable repair parts represent the most expensive repair part approach, yet the reduction in other support resource requirements that this approach permits frequently makes it desirable.

Another situation in which increased repair part costs sometimes result in reduced life cycle support costs occurs when relatively expensive, high-reliability parts are used rather than parts of lesser reliability which, for convenience, will be called standard parts in the discussion that follows. However, in some cases a double payoff can be realized from this appreach, with both repair parts and the remaining life cycle costs decreasing. When considering high reliability versus standard parts, one fact is constant—a high-reliability part costs more than a standard part. All other factors bearing on the consideration are variable and dependent upon previously discussed parameters.

An example of the considerations involved in a high-reliability versus standard repair part trade-off will demonstrate the important costs that must be considered. A constant maintenance concept is assumed. The first and most significant repair part cost involves initial stockage. The range of repair parts required by the two candidates probably will be about the same at each involved maintenance level. The range of high-reliability parts will not be appreciably less because of a requirement for insurance items. On the other hand, the depth of high-reliability parts will be appreciably decreased. The total number of required high-reliability parts will definitely be less. The initial stockage costs of these parts may be greater or less, depending upon unit costs of the two candidates and the differential between required quantities. Resulting costs are nonrecurring.

Considering recurring costs, a smaller number of high-reliability parts will be replenished during the materiel life cycle. Whether these will cost less than standard parts will depend on the previously mentioned factors. A more important recurring cost concerns reduced maintenance requirements. High-reliability parts will have a favorable impact on all other support resources except support equipment, publications, and facilities, which will remain unchanged. A final recurring cost to consider is supply management. Parts in either candidate category which are not in the supply inventory will generate these additional costs. The annual recurring cost totals for all candidates are multiplied by the number of years the materiel will be in the inventory, and these are added to the previously determined nonrecurring costs. At this point, a repair part decision can be made.

The foregoing example was based on a constant maintenance concept to simplify the discussion. In some cases, the use of high-reliability parts will permit the elimination of some maintenance levels, with resultant reductions in personnel, support equipment, and facility requirements.

Similar trade-offs are required to evaluate repair part cost implications of disposable versus maintainable modules, modules of varying complexity, etc.

3-5.9 ACCESSIBILITY OF PARTS AND ASSEMBLIES

Accessibility can be defined as the relative ease with which an assembly or component can be approached for repair, replacement, or servicing. Poor accessibility makes maintenance more difficult and time consuming, and tends to degrade maintenance reliability. The ideal situation, from an accessibility point of view, would be to have all assemblies, components, etc., in a materiel item completely exposed and arranged in a manner that permits repair, replacement, or servicing with no interference from any other assembly or component. Since this situation cannot be realized in military materiel, maintenance engineering assists maintainability in establishing optimum accessibility requirements.

Optimum accessibility can be defined as that accessibility which permits materiel to satisfy its operational requirements with the least expenditure of time spent in gaining access for maintenance. In other words, since it is not possible to provide equal across-the-board accessibility, the highest feasible degree of accessibility should be provided for frequently required maintenance actions, and a lesser degree for the others. The net result is less total time spent in gaining access for maintenance.

Optimum accessibility requirements must be based on a consideration of predicted assembly and component failures. All other things being equal, a general accessibility balance between items can be maintained by making required access times inversely proportional to predicted item failure rates. This assumes that the functions of the items are equally critical, which is not always the case, and that the operational requirement for availability remains satisfied.

3-5.10 ACCESSIBILITY OF LUBRICATION AND SERVICE POINTS (Ref. 1)

Virtually all military materiel is lubricated and serviced on a periodic basis. Properly performed, these activities will help to insure long periods of otherwise maintenance-free operation. Improperly performed, they can result in catastrophic failures. Improper performance is most apt to result from inaccessibility, because with accessibility, most lubrication and servicing actions are straightforward. Accessibility also results in reduced maintenance time requirements.

Lubrication and service points are accesses within physical structures, and it is vital that the points be included in design before materiel is fabricated. Equally important, they must be designed to provide adequate accessibility. Because of the importance of these points to maintenance, maintenance engineering pays particular attention to this area of design, and makes maximum use of mock-ups and models, as well as drawings and discussions with design engineers, to verify that unforeseen lubrication and service problems will not be encountered by using personnel.

Grease fittings should be standard and readily and easily accessible. When a grease fitting is not easily accessible, extension lines should be built into the equipment to bring the grease fitting to an accessible location on the outside of the. equipment. The fitting end of the line should be securely anchored to withstand rough use. Fittings of the same size and of a standard type should be used throughout the equipment. The use of grease cups, exposed oil holes, and oil cups should be avoided.

Materiel filling and reoiling operations should be rapid and easy. The systems for fuel, exotic fluids and gases, oil, hydraulic fluid, water, compressed air, etc., should be designed to permit the most rapid, overall inspection. The necessity for opening doors and hatches for inspection or to gain access to service points or filler caps should be reduced. Servicing points for checking, filling, and draining fuel, lubricant, hydraulic fluid, coolant, etc., should be readily accessible but protected. The need for special tools should be eliminated whenever possible.

3-5.11 PROTECTION OF SOLID-STATE COMPONENTS

The increasing use of solid-state components such as diodes, transistors, integrated circuits, and other specialized devices is prompted by the design efficiencies they offer. Physically small compared with their vacuum tube predecessors, they also typically operate at lower power levels, are significantly more reliable, and are less prone to long-term performance deterioration.

Solid-state components, however, are highly susceptible to immediate and permanent damage inflicted by abnormally high operating voltages or power dissipation requirements. For this reason, it is necessary to insure that newly evolving solid-state equipment designs incorporate appropriate protective features. Generally speaking, these features are concentrated in the design of the power supply, which provides secondary operating voltages used by solid-state devices throughout the design, and include overvoltage and overcurrent protection, and filtering and/or decoupling for purposes of suppressing transients. Popular descriptive terms for circuits that provide overvoltage and overcurrent protection are crowbars and current limiters, respectively.

It is a maintenance engineering responsibility to insure that all new solid-state designs incorporate such features. Maintenance engineering also is responsible for insuring that protective features necessitated by the particular application or operating environment of the equipment are provided. Examples of such features include extensive component derating, shielding of equipment enclosures against the effects of external emitters of electromagnetic fields or other unwanted radiation, and circuits for the suppression or avoidance of transients that may occur on primary power and input/output signal interfaces.

The limitations of solid-state devices relative to power dissipation have basis in the physics of their internal junctions, and the upper operating temperatures these junctions can withstand without failure. For this reason, it is also important that equipment design incorporate combinations of conductive, convective, and radiating cooling mechanisms that are compatible both with the solid-state devices being used and with the overall equipment intended operational application. When there is doubt as to the adequacy of such features, maintenance engineering should consult with thermal design specialists.

Improved equipment operating or maintenance practices also may prompt the need for protection of solid-state components. Because one form of voltage overstress results from reversal of applied operating or signal voltages, the use of connector keying schemes and steering diode circuits may be warranted.

In short, there are two classes of protective measures that should be applied to the design of solid-state materiel: those necessitated simply because it is solid-state, and those necessary to protect the materiel against the operating and maintenance environment to which it will be exposed.

3-5.12 MAINTENANCE-FREE EQUIPMENT

The simplest maintenance action requires personnel and publications, probably requires support ,equipment and repair parts or consumables, and may require facilities. Clearly, the elimination of maintenance by designing materiel with maintenance-free assemblies and components should be requested by maintenance engineering on a priority basis. When the acquisition cost of the maintenance-free materiel exceeds that of the maintainable materiel, requests should be accompanied by life cycle cost trade-offs that demonstrate the desirability of the maintenance-free approach. Additionally, since maintenance itself is not 100 percent reliable, and many maintenance actions can result in damage to adjacent assemblies and components, the reliability advantages of maintenance-free equipment should be emphasized.

A number of types of maintenance-free assemblies currently exist and have been proved in use. Others will be forthcoming as advances are made in material technology and innovative design and manufacturing techniques. At the start of each new materiel program, maintenance engineering should survey the Army, other services, and industry for any maintenance-free assemblies and components that are applicable to the new materiel, and request their incorporation into design.

The two main categories of maintenance-free assemblies and components currently available are those that require no lubrication and those that require no adjustments. In the first category are fixed joints, factory sealed bearings, alloyed bearings with self-oiling properties, plastic bearings, and chemical lubricants introduced into cooling systems. Self-adjusting brakes and self-adjusting components that use spring tension or compression, hydraulic pressure, etc., comprise the second category. Another wav to eliminate maintenance reauirements not associated with the two main categories is to design assemblies for a specific lifespan, and then to discard them. This is a disposable module approach, with disposal based on calendar time rather than on failures.

3-5.13 ELECTRICAL CABLES AND WIRES (Ref. 1)

Cables, wires, and connectors comprise a vital portion of most materiel items. When properly designed and installed, they simplify the maintenance of the remainder of the materiel and pose minimum maintenance problems within themselves. Maintenance engineering evaluates the design and installation of cables and connectors to insure that proper consideration has been given to features that impact maintainability and reliability, and makes appropriate design recommendations. For additional guidance on cables, see Ref. 19.

3-5.13.1 Cable Design

The following recommendations should be observed when designing and using cables:

a. Cables should be long enough so that:

(1) Each unit can be checked in a convenient place (extension cables should be provided when necessary).

(2) Units in drawers and slide-out racks can be pulled out to be worked on without breaking electrical connections.

(3) Connectors can be reached easily for replacement or repair.

(4) Units that are difficult to connect where they are mounted can be moved to a more convenient position for connecting and disconnecting.

b. The length of cables should be the same for each installation of a given type of electronic equipment if the circuit might be affected by differences in the length of the cable. (Even if a unit can be adjusted to compensate for differences in the length of the cable, the use of different lengths of cable means that adjustments made on the bench might be out of tolerance when the unit is installed.)

c. Cable harnesses should be designed so that they can be built in a shop or factory and installed as a package.

d. Cables should "fan out" in junction boxes for easy checking, especially if there are no other test points in the circuits. Each terminal in the junction box should be clearly labeled and easy to reach with test probes.

e. Preformed cables should be used when possible. They permit flexible, more efficient assembly methods and minimize the chances of making wiring errors. They also permit testing and coding of the entire cable before installation. Once the cable is placed in position on the chassis, the leads can be connected without the usual interference and confusion caused by stray wires.

f. The use of a clear plastic covering to insulate leads and cables should be considered so that breaks in internal wiring can readily be seen.

g. When polyvinyl wire is used, care should be taken so there will be no cold flow of the insulation due to tightness of lacing or mounting.

h. Neoprene-covered rather than aluminum-sheathed cable should be used in areas where intense vibration or corrosive substances may cause failures.

i. High-temperature wire should be used when wires are routed near ducts carrying pressures over 50 psi and/or temperatures above 200°C **(392°F).**

j. Metallic shielding unprotected by outer insulation should be secured to prevent the shielding from contacting exposed terminals or conductors.

k. Insulated wire or cable should be color or number coded in accordance with applicable military standards.

3-5.13.2 Cable Routing

The following recommendations should be observed:

a. Route cables so that they:

(1) Are not pinched by doors, lids, and slides.

(2) Are not walked on or used for handholds.

(3) Are accessible to the technician; i.e., are not under floorboards, behind panels or components that are difficult to remove, or routed through congested areas, and need not be bent or unbent sharply when connected or disconnected.

b. Design cables or lines that must be routed through walls or bulkheads for easy installation and removal without the necessity for cutting or compromising the integrity of the system.

c. Route cables to avoid close contact with tubes, transformers, or rectifiers so that cables will not be damaged by overheating.

d. Provide guards or other protection for easily damaged conductors such as waveguides, high frequency cables, or insulated high-voltage cables.

e. Protect electrical wiring from contact with fluids such as grease, oil, fuel, hydraulic fluid, water, or cleaning solvents. These may damage insulation and result in injury to personnel.

f. Provide a means for keeping cables and lines off the ground. This is especially important in areas where ice and snow may cover the lines for long periods, making them inaccessible for maintenance.

g. Where cable connections are maintained between stationary equipment and sliding chassis or hinged doors, provide service loops to permit movement, such as pulling out a drawer for maintenance, without breaking the electrical connection. The service loop should have a return feature to prevent interference when removable chassis are replaced in the cabinet.

h. Provide storage space for long electrical cables that are a part of ground power, service, and test equipment.

i. Precautions should be taken to protect the insulation at the ends of cables from moisture. Moistureproof jacketing that will withstand the required temperature range and mechanical abuse should be used.

3-5.13.3 Connectors

The following recommendations should be observed when providing for connection and disconnection of cables:

a. Use plugs and matching receptacles that make it impossible to connect the two incorrectly. For example, use different sizes of plugs for nearby connections, use different keys or alignment pins, and/or color-code or paint stripes, arrows, or other information on each plug and the receptacle to which it belongs.

b. Clearly identify, by number or letter, each pin on each plug.

c. Use quick-disconnect plugs or plugs that can be disconnected with no more than one turn, rather than plugs with fine threads that require many turns.

d. Use plugs in which the aligning pins or keys extend beyond the electrical pins. This arrangement protects the electrical pins from damage caused by poor alignment or twisting of the plug when it is partially inserted. Use sheaths longer than the electrical pins to avoid accidental shorts or grounds.

e. Avoid symmetrical arrangements of aligning pins or keys so that plugs cannot be inserted 180 deg from the correct position.

f. Locate connectors far enough apart so that they can be gripped firmly for connecting and disconnecting while the technician wears arctic mittens.

g. When a part of a machine or system can be removed for maintenance, insure that cables that connect the removable part with the rest of the machine or system have plugs and receptacles that will disconnect before the cables will break.

h. Use plugs with integral test points for each input and output that cannot otherwise be checked easily. As an alternative, provide a test point adapter for insertion between plugs and receptacles.

i. Use fewer plugs with many pins rather than more plugs with fewer pins; it takes about the same amount of time to connect a plug with many pins as it does one with a few pins. However, cables must not be permitted to become so large that they cannot be handled easily.

j. Use connectors in which electrical contacts cannot be shorted by external objects.

k. Provide plugs with self-locking safety catches rather than safety wiring. If safety wiring is a requirement, design holes and slots for most efficient and rapid attachment of the safety wire.

l. Insure that plugs and leads do not transmit stored charges while being disconnected.

m. Design lead pins and plugs so that they are strong enough not to be damaged by rough use. Avoid the use of miniature plugs where pins can be easily bent upon mating, thus causing a short circuit.

n. On a given materiel system, standardize wiring connectors used in identical types of electrical equipment to reduce errors in wiring during installation or maintenance.

o. Use individual power disconnects so that power can be turned off in one part of the system without having to disconnect the entire system.

p. Label electrical cable connectors with current and voltage values. Include on the label a designation of the source of the current, such as line, station, generator, or auxiliary power unit.

q. Clearly label power receptacles for primary, secondary, or utility systems in order to prevent personnel injury or equipment damage.

r. Provide captive covers to protect connector ends from moisture and other foreign matter.

3-5.14 DESIGN TO SERVICE WITH STANDARD TEST EQUIPMENT

The decision regarding the proper type of test equipment to be used must be made in the early stages of materiel design—as early as the drafting of the maintenance plan will allow—and should be firm by the development phase. The factors involved in this decision include the mission and operational characteristics of the materiel, the anticipated reliability, the maintenance structure, the equipment and personnel available to the user, the operational environment, the logistic support requirements, the development time, and the cost.

The four general types of test equipment (defined in par. **3-4.7.3)** are special-purpose, general-purpose (standard), built-in, and automatic. When operational requirements and materiel complexity do not dictate built-in or automatic test equipment, there is a probability that standard test equipment will prove to be the most cost-effective choice. Maintenance engineering participates in test equipment cost trade-offs and makes appropriate design recommendations.

If built-in and automatic types of test equipment are not mandatory selections as a result of operational requirements and materiel complexity, they normally can be eliminated from consideration on the basis of costs. The very fact that neither is a mandatory requirement indicates that the materiel under consideration has no more than moderately complex circuitry and that maintenance downtime is not an overriding consideration. It will be assumed that these two types of test equipment have been eliminated from consideration, and the remainder of the discussion will be limited to general-purpose versus special-purpose equipment.

The most significant advantages of general-purpose test equipment accrue when the equipment can be used without adapters. In such cases, procurement time is minimal, development costs are avoided, and the logistic system can accept additional units of the equipment with no impact on publications pertaining to test equipment maintenance and operation, no impact on skill levels, and no impact on supply management. If adapters are required, these advantages are diminished in proportion to the number and complexity of the types of adapters and the total number of adapters that must be introduced into the supply inventory.

The advantages of special-purpose test equipment lie in the areas of test equipment use and prime materiel design. This type of test equipment is less complex to use in making tests, and consequently, training, publications, and maintenance time requirements for the user are minimized. Additionally, there are fewer probabilities of damaging the test equipment and the item being tested. With regard to prime materiel design, the interface between special-purpose test equipment and the materiel can be optimized. A requirement to use standard test equipment constrains and sometimes greatly complicates materiel design because signal outputs must be compatible with existing test equipment.

As a general rule, it may be stated that standard test equipment is always the best choice when relatively simple point-to-point testing is required. As testing requirements become more complex, test equipment selection decisions can be made only after exhaustive cost-effectiveness trade-offs that consider the many factors unique to the requirements of the materiel being studied. All decisions must be made prior to the start of the development phase.

3-6 MAINTENANCE ENGINEERING RESPONSIBILITIES IN DEVELOPING REQUIREMENTS OF HUMAN FACTORS IN DESIGN (Ref. 1)

The human factors engineering element in a materiel program has prime responsibility for insuring that an optimum interface exists between human capabilities and materiel design features that affect human actions required to operate and maintain the materiel in its operational environment. Maintenance economy and efficiency are significantly affected by how well this function is accomplished. Maintenance engineering works closely with human factors to optimize the interface. Maintenance engineering provides historical data, experience, and judgment, monitors design, and, in particular, evaluates the human factors aspects of mock-ups and models. The goal is to establish design requirements before hardware is fabricated.

An understanding of the background of human factors engineering and of data sources and data pertaining to the characteristics, capabilities, and limitations of humans will assist maintenance engineering in working more effectively with human factors personnel. The discussion that follows presents an overview of the subjects.

3-6.1 HUMAN FACTORS ENGINEERING

Human factors engineering is a discipline that relates man's size, strength, and other capabilities to the necessary work. Failure to consider human factors will result in increased maintainability problems. Human factors engineering began when psychologists were called in to make critical investigations of, for example, physical limitations in aviation and behavior in naval combat information centers. Its goal was to provide designers with the probable characteristics of the individuals who would operate and maintain the machines and equipment.

Today, human factors engineering draws on psychology, physiology, physics, anthropology, and medicine, and requires close alliance between engineers and psychologists. Human factors engineers consider complex military equipment as man-machine systems, including as design considerations the capabilities and limitations of man under various conditions.

3-6.2 HUMAN BODY MEASUREMENTS (ANTHROPOMETRY)

One important consideration in designing for maintainability is information on body measurements. This information is required in the earliest design stages to insure that equipment will accommodate operators and maintenance men of various sizes and shapes. This paragraph describes the sources of anthropometric measurements available to the designer, indicating some of the types of information and giving examples of the more common measurements.

3-6.2.1 Sources and Use of Information on Body Measurements

The designer has two basic sources of information on body measurements: anthropometric surveys, in which measurements of a sample of the population have been made, and experiments under circumstances that simulate the conditions for which he is designing. Which of these sources or which combination is used depends on the availability of adequate anthropometric surveys and on the cost of experiments in both time and money.

Anthropometric data usually are presented in percentiles, ranges, and means (or medians). With information of this type, the designer, who usually will not be able to accommodate all possible sizes, can decide where to make the cutoff. He must, of course, design equipment to insure operability and maintainability by at least 90 percent of the user population. The design range includes at least the 5th to 95th percentiles for design-critical body dimensions (Ref. 12).

3-6.2.2 Types of Body Measurements

Both ,static and dynamic body measurements are important to the designer. Static measurements include everything from measurements of the most gross aspects of body size, such as stature, to measurements of the distance between the pupils of the eyes. The measurements required will depend on the particular equipment being designed. The more common static measurements, having received the most attention from anthropometrists, are most readily available and are the most reliable because of the large and numerous samples on which they are based.

Unlike static body dimensions, which are measured with the subject in rigid standardized positions, dynamic body measurements usually vary with body movements. Dynamic measurements include those made with the subjects in various working positions, and functional arm and leg reaches. Static dimensions corresponding to functional reaches would be anatomical arm and leg lengths. Dynamic dimensions in equipment design relate more to human performance than to human "fit".

3-6.3 HUMAN SENSORY CAPACITIES

The data that follow are presented to assist in a better understanding of the sensory capacities of the maintenance man as they apply to color-coding, shape-coding, parts identification and noise.

3-6.3.1 Sight

Sight is stimulated by electromagnetic radiations of certain wavelengths, commonly called the visible portion of the electromagnetic spectrum. The various hues (parts of the spectrum), as seen by the eye, appear to differ in brightness. In daylight, for example, the eye is most sensitive to greenish-yellow light that has a wavelength of about 5500 angstrom units. The eye also sees differently from different angles.

One can perceive all colors while looking straight ahead. Color perception, however, begins to decrease as the viewing angle increases. Green disappears at about 40 deg off the level view in the vertical plane, and red disappears at above 45 deg. Yellow and blue can be distinguished over a larger area. Therefore, if equipment has color-banded meters or warning lights of different colors that are in such a position as to be near the horizontal or vertical limits of color differentiation, the user will not be able to distinguish one color from another.

Color-weak people (so few people are absolutely color blind that they can be ignored) do not see colors the way "normal" people do, and any color-coding will be lost on them. Therefore, colors should be selected that color-weak people do not confuse, such as yellow and blue, or color-coding should be augmented with shape-coding.

At night, or in poorly illuminated areas, color makes little difference, and at a distance, or if the point source is small (such as a small warning light), blue, green, yellow, and orange are indistinguishable; they will appear to be white. A further phenomenon of sight perception of light is apparent reversal of color. When an individual stares at a red or green light, for instance, and then glances away, the signal to the brain may reverse the color. This phenomenon has caused accidents. Too much reliance should not be placed on color when critical operations may be performed by fatigued personnel. Whenever possible, red filters having wavelengths longer than 6500 angstrom units should be used. If this is not possible, then warning lights, at least, should be as close to red as possible. Colors such as red amber or reddish purple are satisfactory.

3-6.3.2 Touch

As equipment becomes more complex, it is necessary that the maintenance man use all his senses most efficiently. Man's ability to interpret visual and auditory stimuli is closely associated with the sense of touch. The sensory cues received by the skin and muscles can be used, to some degree, to convey messages to the brain that relieve the eyes and ears of part of the load they otherwise would carry. For example, different control knob shapes can be recognized easily by touch alone. Selected knob shapes can be adapted for use when the user must rely completely on his sense of touch, as, for instance, when a knob must be put in an out-of-the-way place.

3-6.3.3 Noise

Man's reaction to noise extends beyond the auditory system: it can contribute to such feelings as well-being, boredom, irritability, or fatigue. Work requiring a high degree of muscular coordination and precision, or intense concentration, may be affected adversely by noise. An individual exposed to sound that exceeds a level of about 120 dB, can begin to "feel" the sound physically, and at levels above 130 dB, might experience pain.

In addition to affecting the performance of maintenance technicians in tasks not dependent upon auditory tasks, excessive noise can make oral communications ineffectual or impossible, and can damage hearing. Consequently, the interior noise levels in maintenance or control areas (vans, huts, etc.) in which communication of information, either direct or electrical, is critical, should not exceed levels that permit reliable communications with raised voice at a distance of 3 to 4 ft.

3-6.3.4 Vibration and Motion

Vibration may be detrimental to the maintenance technician's performance of both mental and physical tasks. Large amplitude, low frequency vibrations contribute to motion sickness, headaches, fatigue, eye strain, interference with depth perception (depth perception fails at frequencies of 25 to 40 Hz and again at 60 to 90 Hz), and interference with the ability to read and interpret instruments. As the amplitude of vibration decreases and the frequency increases, these symptoms become less pronounced. However, vibration of low amplitude and high frequency can be fatiguing.

3-6.4 HUMAN REACTION TO EXTREME TEMPERATURES

Although the effects of temperature on human performance are not completely understood, it is known that certain temperature extremes are detrimental to work efficiency. As the temperature increases above the comfort zone, mental processes slow down, motor response is slower, and error likelihood increases. As the temperature decreases below the comfort zone, physical fatigue and stiffening of the extremities begin.

3-6.4.1 Heat

The operational efficiency of personnel decreases when temperature and humidity combine to make a physically uncomfortable environment. In the case of maintenance, the decrease is marked by increased maintenance times and an increase in maintenance errors. When feasible, built-in or portable air conditioning should be supplied for personnel performing maintenance in enclosed areas when the temperature is above 90°F.

3-6.4.2 Cold and Windchill

Maintenance personnel on duty in the Arctic are handicapped physically and psychologically. When a man is cold, or afraid of the cold, his efficiency and incentive may be impaired. In spite of the best arctic clothing, it has been found that the suffering experienced by personnel increases rapidly as the temperature drops below −10°F. Personnel need all their energy to use tools of any kind in the open. Without shelter and heat, most adjustments are impossible. A worker wearing heavy gloves out in the open finds even the simple task of removing or inserting screws extremely difficult, and with screws less than 0.25 in. in length, impossible. When a worker is properly dressed, he can perform down to some point between 32" and 0°F for 30 min without interference from the cold itself.

The physiological effects of cold temperatures are greatly magnified by wind. For example, exposed flesh freezes at about −40°F in a wind of 1 to 2 mph, and at about 18°F in a wind of 40 mph. Windchill charts have been developed that portray the comparative severity of temperature and wind combinations.

3-7 HISTORICAL PERFORMANCE DATA AND MILITARY HANDBOOK REFERENCE MATERIAL AS AIDS TO MAINTENANCE ENGINEERING EVALUATION OF DESIGN

Design evaluation is a continuing maintenance engineering function, which is comprised of first determining what to evaluate, and then establishing evaluation criteria and performing the evaluation. All actions are accomplished for the fundamental purpose of assuring that the developed materiel will be easy and economical to maintain and will generate lowest life cycle costs. Three of the basic tools available to assist in design evaluation are specifications, historical performance data, and handbooks.

Specifications, either quantitative or qualitative, that establish maintenance parameter requirements indirectly identify the materiel design features that must be evaluated. For example, a specified mean time to repair leads to an evaluation of parameters such as reliability, diagnostics, accessibility, and packaging, to determine whether or not the time can be met. This type of evaluation will not result in design improvement if the specification is satisfied, and could result in the acceptance of a design that is not optimum. Even if the time is met, there may be a better design. The determination of whether or not a qualitative specification requirement is satisfied forces a more thorough design evaluation. If a requirement is established for minimum skills at the organizational level, it is necessary to evaluate all design alternatives to determine whether or not the requirement is satisfied. This automatically will lead to the selection of the best design.

Specification requirements always must be satisfied, but specifications alone will not identify all materiel design features that must be evaluated, and will provide no evaluation criteria. Historical data and handbook data must be used to augment specifications in identifying materiel design features to evaluate, and the data in themselves comprise powerful evaluation tools.

Most Army materiel is evolutionary rather than revolutionary in design. The same may be said for operational and support concepts. It is these facts that make historical data so valuable to design evaluation. The manner in which deployed materiel has performed and the support it requires certainly should be given consideration equal to the predictions of how similar but improved materiel will perform and of its maintenance requirements. Additionally, many components and assemblies in deployed materiel will be identical to those planned for new materiel. In these cases, assuming identical natural and induced use environments, historical data provide the ultimate evaluation criteria.

During materiel design, predicted reliability probably has more impact on the planned support subsystem than any other parameter. The predicted frequency and distribution of failures resulting from unreliability dictate many maintainability and support resource requirements. Maintenance engineering should fully exploit historical reliability data in evaluating new designs. Each reliability success and each problem in deployed materiel identify an area to be evaluated in new materiel. Components and assemblies with a proven history of reliability should be favored over proposed improved items with better operational characteristics, unless there is satisfactory evidence that the proven items cannot satisfy operational requirements. Items with a poor reliability history should not be used. Predicted reliabilities for end items should be evaluated against occurrences in the field and appropriate K-factors (par. 3-34 derived for determining the support resource requirements that the proposed materiel truly generates.

Historical maintainability data should be exploited in the same manner as that described far reliability data. Proven maintainability features should be retained in the new design, and problem features eliminated. Historical maintainability data coupled with resource utilization data provide an extremely valuable tool for determining support resources that the new materiel will require. There is no better information available that can be used for predicting life cycle support costs.

Like historical data, military handbooks assist in both identifying design features to evaluate in new materiel and in conducting the evaluation. Handbooks that deal with basic engineering, as well as with reliability, maintainability, and human factors engineering, are available. Some of the handbooks have checklists and other aids that make them very convenient for use in concurrently identifying design features to evaluate in new materiel and in conducting the evaluation. For example, reference to **a** human factors engineering handbook during materiel evaluation will lead to questions concerning the space provided for maintenance personnel, their strength requirements, the proposed working environment, etc. An immediate answer as to the acceptability of the design can be ascertained by comparing what is proposed with the standards established in the handbook.

3-7.1 COMPUTERIZED DATA COLLECTION SYSTEMS

The Army has two computerized data collection methods that are of exceptional value to maintenance engineering in analyzing new designs. These are a maintenance engineering analysis data system and a maintenance management system. The first documents data resulting from design analysis and testing on a development program, and the second contains experience data from operating and maintaining fielded materiel. Taken together, the data collected from these two systems provide an audit trail from design, to predicted performance, to actual performance in the field. The paragraphs that follow, discuss the nature **of** the two collection methods.

3-7.1.1 Maintenance Engineering Analysis System (Ref. 6)

Maintenance engineering analysis data systems typified by the logistic support analysis data system described in par. **5-3** contain, in large part, predicted performance data based on design analysis. Performance, in this case, refers to maintenance requirements that deployed materiel will generate and the manner in which resources will be used to perform the maintenance. Predicted operator performance is also a part of the data.

Maintenance engineering is responsible for the data system, and is the source of all data elements except those pertaining to operational, deployment, and design parameters. Maintenance engineering influences design parameters, but the primary responsibility for their determination lies with system and design engineering elements. Maintenance engineering analyzes operational, deployment, and design parameters, and predicts the frequency, duration, and nature of corrective and preventive maintenance that must be performed at all maintenance levels. Concurrently, support resources required at all maintenance levels are predicted.

Predictions are refined with test data as they become available. All predictions to this point pertain to elements of a materiel system and must be summarized and manipulated to provide meaningful system data.

Due to the mass of data generated on a major materiel program and the fact that these data are being continuously refined, a computer program is used for data manipulation. Normally, the program is maintained by a contractor through the development phase and, subsequently, by the Army. The major source of program changes after development is materiel modifications.

The data system can provide detailed operational and maintenance data on any maintenance significant item or group of items, **or** on the total materiel system. Virtually any operational or-maintenance factor that can be measured after deployment can be predicted by the data system. For example, operational availability, repair part consumption, and support resource utilization rates can be predicted for an assembly or for the total system.

Maintenance engineering analysis predictions serve as reference points for evaluating the performance of deployed materiel. Any field experience that shows under- or over-achievement of predicted performance generates a requirement for analyses, trade-offs, and possible corrective action.

3-7.1.2 Maintenance Management System (Refs. 7, 8)

The Army maintains a maintenance management system that records and reports selected elements of information pertaining to the deployed materiel. Raw data generated at the user and support maintenance levels are entered onto prescribed forms. Commanders at the field level process data relating to expenditure of maintenance resources and materiel readiness indicators, and forward selected maintenance data to a national level data bank. Analyses, summaries, and reports subsequently are furnished to the national level materiel managers for their use in improving the materiel readiness condition of Army materiel in the hands of the user.

The basic data in the system represent day-to-day experience of using organizations in operating and maintaining materiel. Data are recorded on assemblies, end items, and systems. Reduced data provide quantitative information such as:

a. Materiel reliability, maintainability, and availability

b. Scheduled and unscheduled maintenance requirements

c. Repair part consumption

d. Utilization rates for personnel, materiel, and facilities.

Typical uses of the reduced data are to validate maintenance engineering analysis predictions, identify problems with regard to current support resources, forecast resource requirements, and to detect trends that indicate a need for materiel modification, or that materiel is nearing the end of its useful life. Additionally, the data are used to evaluate new materiel concepts and designs, and to estimate life cycle support costs for new materiel.

3-7.2 MILITARY HANDBOOKS ON ENGINEERING DESIGN, RELIABILITY ENGINEERING, MAINTAINABILITY ENGINEERING, AND HUMAN FACTORS ENGINEERING

Numerous military engineering handbooks have been published, and new ones are being published annually. Handbooks are published by all of the military services, and some are sponsored by the Department of Defense. Each handbook contains information and data that can aid in the development of cost-effective military materiel. The handbooks are used mainly by military and contractor engineers, but are also of value to management personnel.

The stated purpose of Army handbooks, and this can be considered to be a universal purpose, is to:

a. Conserve time, materials, and funds by outlining the approaches to the problems most likely to result in successful conclusions.

b. Provide a reference of fundamental design information not readily available elsewhere that will facilitate the evolution of new designs.

c. Generate, compile, and maintain an up-to-date set of formulas, tables, and values useful in the design of Army materiel.

d. Preserve a record of Army design experience, forestalling duplication of past experience and work. The designer should be aware not only of current new developments but also of concepts advanced in the past that have been tried and laid aside in order that worthy additions to the state of the art are not lost and worthless ones are not tested again.

e. Preserve unique technical knowledge that otherwise would be lost when design engineers resign, retire, or die.

f. Provide orientation and guidance for new personnel and for Army contractors.

g. Communicate to design engineers, in capsule form, the requirements and disciplines of the allied technical fields with which they must be concerned.

h. Permit design of Army materiel to proceed at an accelerated rate under conditions of mobilization or other emergency when experienced designers 'are overtaxed with the emergency requirements.

Engineering handbooks have been published by one or more of the services on virtually all subjects in which maintenance engineering has an interest. An appreciation of this statement may be gained by examining the list of current and proposed AMC handbooks on the inside back cover of this book. It will be noted that some of these handbooks are applicable to broad design disciplines and some to specific design problems associated with Army materiel. The other services have used a similar approach in their handbook programs, and the number of handbooks that they have published is comparable. Since many design principles and design problems are applicable to materiel used by each of the services, it follows that maintenance engineering will find information applicable to Army materiel in the handbooks of other services, and should obtain and use this information.

Since some handbooks are written on specific subjects such as the design of gun tubes, and others are written on general subjects such as microelectronic design, reliability, maintainability, and human factors, it is not feasible to describe the contents of a typical handbook. Consequently, in order to discuss the contents of handbooks, the contents of several that were selected at random will be described in the paragraphs that follow.

The contents of two design handbooks, one dealing with a specific problem and one dealing with a general design subject, will be discussed first. The former is an AMC handbook on the subject of hardening weapon systems against radio frequency energy (Ref. 9). This book thoroughly covers the theoretical and practical aspects of the problem and its solution from an engineering design point of view. It briefly addresses reliability, and makes no mention of maintainability, human factors, and maintenance. However, from an examination of the design recommendations, it is clear that the authors considered reliability, maintainability, and logistics. This book would be of use to maintenance engineering, but it would have to be studied. There is no quick way to find maintenance related subjects.

An Air Force handbook on the general design subject of microelectronics (Ref. 10) deals with the theoretical and practical aspects of designing components, circuits, and subsystems. Separate sections are devoted to reliability, maintenance, and logistics. Information pertaining to maintenance engineering could be obtained much more rapidly from this handbook than from the previously described AMC handbook.

A Navy handbook on reliability (Ref. 11) provides guidance on the conduct of a materiel life cycle reliability program with emphasis on the earlier life cycle phases. The theoretical and practical aspects of establishing reliability specification requirements and of accomplishing allocations and predictions are discussed, as well as estimating time and fund requirements for a reliability program. A section is devoted to the mathematics of reliability. The handbook is not oriented towards specific materiel. For example, its treatment of redundancy could apply to electric generators or diodes. This handbook would prove valuable to maintenance engineering in understanding how and why a materiel reliability program is conducted. It would not assist readily in evaluating the reliability aspects of materiel design other than by providing ready reference to reliability mathematics.

The maintainability handbook selected was published by the U S Army Materiel Command (Ref. 1). This handbook thoroughly covers the practical aspects of maintainability, and provides coverage, to a lesser depth, on human factors, safety, and reliability. Maintainability design features are discussed, first with regard to their general application to design, and subsequently with regard to their application to specific Army materiel. The handbook has numerous checklists, tables, illustrations, etc., which make it a valuable and efficient tool for evaluating materiel design.

A Department of Defense standard (Ref. 12) establishes general human engineering criteria for military materiel. It is published in handbook format, and is representative of human engineering handbooks issued by the services. The standard establishes requirements for controls, displays, work space, work environment, and other madmachine interfaces, and briefly addresses maintainability and safety. Virtually all of the requirements are quantitative. Charts, tables, and illustrations assist in rapidly interpreting the requirements. The book is a valuable maintenance engineering tool.

A final type of handbook that may be encountered is sponsored by the Department of Defense and published by a military service. An example is a handbook on maintainability prediction (Ref. **13**). This handbook presents the mathematics and procedures associated with several maintainability prediction techniques, and gives examples of their application. This handbook is valuable to maintenance engineering.

It may be seen that useful maintenance engineering information is apt to exist in most military handbooks. Since maintainability and maintenance engineering are so closely associated with regard to materiel design requirements, maintainability handbooks normally will be the most useful to maintenance engineering. Human engineering handbooks would probably rank second in value. It is not safe to generalize on the utility of the other types of handbooks since their value would depend on the purpose of the book and whether the authors chose to make maintenance related matters a separate part of their discussion.

REFERENCES

1. AMCP 706-134, Engineering Design Handbook, *Maintainability Guide for Design.*
2. Richard B. Dillard, *Reliability for the Engineer,* Martin Marietta Corporation, Orlando, Florida, 1965.
3. AR 310-25, *Dictionary of United States Army Terms (Short Title: AD),* 1 June 1972.
4. NAVPERS 15163, *Navy Military Manpower Billet Cost Data for Life Cycle Planning Purposes,* July 1973.
5. *Parts, Materials and Processes Experience Summary,* National Aeronautics and Space Administration, Ames Research Center, Moffett Field, California, 26 February 1973.
6. MIL-STD-1388-1, *Logistic Support Analysis,* 15 October 1973.
7. AR 750-37, *Sample Data Collection, The Army Maintenance Management System (TAMMS),* 24 March 1971.
8. TM 38-750, *The Army Maintenance Management System (TAMMS),* December 1969.
9. AMCP 706-235, Engineering Design Handbook, *Hardening Weapon Systems Against RF Energy.*
10. AFSC DH 1-8, *Microelectronics,* 10 November 1967.
11. NAVWEPS 00-65-502, *Handbook of Reliability Engineering,* 1964.
12. MIL-STD-1472A, *Human Engineering Design Criteria for Military Systems, Equipment and Facilities,* 15 May 1970.
13. MIL-HDBK-472, *Maintainability Prediction,* 24 May 1966.
14. AMCP 706-115, Engineering Design Handbook, *Environmental Series, Part One, Basic Enwironmental Concepts.*
15. AMCP 706-116, Engineering Design Handbook, *Environmental Series, Part Two, Natural Enwironmental Factors.*
16. AMCP 706-117, Engineering Design Handbook, *Environmental Series, Part Three, Induced Environmental Factors.*
17. AMCP 706-118, Engineering Design Handbook, *Environmental Series, Part Four, Life Cycle Environments.*
18. AMCP 706-119, Engineering Design Handbook, *Environmental Series, Part Five, Glossary of Environmental Terms.*
19. AMCP 706-125, Engineering Design Handbook, *Electrical Wire and Cable,*
20. AMCP 706-192, Engineering Design Handbook, *Computer Aided Design of Mechanical Systems.*

BIBLIOGRAPHY

TM 38-710, *Integrated Logistic Support Implementation Guide for DoD Systems and Equipment,* March 1972.

NAVORD OD 39223, *Maintainability Engineering Handbook,* 1 February 1970.

AD-866 818, *Maintainahlity Engineering Design Notebook,* Rome Air Development Center, Griffis Air Force Base, New York, January 1970.

MIL-HDBK-758, *Human Factors Engineering Design for Army Materiel.*

Human Engineering Guide to Equipment Design (Revised Edition), Army, Navy, and Air Force, 1972.

MIL-STD-1474 (MI), *Noise Limits for Army Materiel,* 1 March 1973.

U S Army Natick Laboratories Technical Report 72-51-CE, *The Body Size of Soldiers, U.S. Army Anthropometry – 1966,* December 1971.

U S Army Natick Laboratories Technical Report EPT-2, *Reference Anthropometry of the Arctic-Equipped Soldier,* August 1964.

CHAPTER 4
MAINTENANCE CONCEPTS

This chapter presents information on several subjects that impact the determination of materiel maintenance concepts. Several quantitative maintenance parameters are defined mathematically. A maintenance procedural model is described, and its application to a deployed Army system is discussed. Maintenance scheduling, maintenance organizations, and support planning are discussed.

4-1 INTRODUCTION

Maintenance is any action taken to retain materiel in a serviceable condition or to restore it to serviceability. It includes inspection, testing, servicing, classification for serviceability, reclamation, repair, overhaul, rebuild, modification, retrofit, calibration, and refurbishment. Thus, the scope of maintenance tasks ranges from simple preventive maintenance services performed by the operator of equipment to complex depot maintenance operations performed in fixed shop facilities.

Each item of deployed materiel is maintained in accordance with a maintenance concept that is established initially during the conceptual phase of a materiel program. Essentially, the concept establishes what, when, how, and where corrective and preventive maintenance is to be performed. The maintenance concept undergoes revision throughout the materiel life cycle. Prior to deployment, it is refined to reflect design changes, test results, and other new information. Subsequently, it may be revised as a result of field experience.

Maintenance concepts are based on tradeoffs and analyses of combinations of materiel design, maintenance actions, and maintenance locations that will satisfy operational requirements at lowest life cycle cost. Maintenance concept decisions are the responsibility of maintenance engineering. Such decisions are extremely important, in that, for a given design, they establish the support resources required at each maintenance location, and, consequently, establish life cycle support costs.

4-1.1 MAINTENANCE LEVELS

The Army has a maintenance support structure into which all materiel maintenance concepts must fit. The basic structure consists of categories or levels of maintenance defined as organizational, direct support, general support, and depot. However, flexibility is permitted and, when it is cost-effective, levels may be combined or not used at all. For example, Army aviation maintenance is being phased to a three-level maintenance concept; namely, aviation unit maintenance (formerly organizational), intermediate support maintenance (formerly direct support and general support), and depot maintenance. Direct and general support maintenance performed at a single maintenance level for some other types of materiel is called field maintenance. The term field maintenance also is used in general reference to direct and general support maintenance levels, when differentiation between them is not relevant to the thought being conveyed.

Of the four basic maintenance levels, the least maintenance capability exists at the organizational level, and the capability increases progressively through direct support, general support, and the depot. Organizational maintenance is the responsibility of the unit commander, who accomplishes the maintenance with the resources under his control. It is comprised of preventive maintenance and relatively simple corrective maintenance. Preventive maintenance is performed on a scheduled basis, and consists of activities such as inspecting, cleaning, servicing, lubricating, and adjusting. Corrective maintenance is performed when materiel performance falls below a specified level, and consists of activities such as diagnosing, removing, repairing, replacing, and testing. Preventive maintenance and corrective maintenance frequently are called scheduled maintenance and unscheduled maintenance, respectively. Materiel availability depends, in part, upon the rapidity with which organizational maintenance is accomplished.

Direct and general support units in the field normally are under control of division and major Army commanders, but their mission is to support the unit commanders. Normally, the direct support unit is geographically close to the using unit, and the general support unit is geographically removed. Also, the direct support unit is more mobile than the general support unit. Items replaced by organizational units are referred to direct support units for maintenance or disposal. Direct support units refer maintenance that they cannot accomplish to general support units. Direct support units exchange items with the using organization, whereas general support units normally return repaired items to stock. Depots are under control of national level materiel managers and designated major oversea commanders. Depots perform maintenance that is designated by maintenance engineering as being uneconomical or technically impractical to perform at lower levels. This maintenance can range from repair of modules, such as printed wiring boards, to overhaul and rebuild of end items. Repaired items are returned to stock.

4-1.2 SUPPORT SYNTHESIS (Ref. 1)

To develop a maintenance concept, maintenance engineering basically must determine the type, duration, and frequency of the maintenance to be performed, and the maintenance level at which it will be performed. As has been indicated, this is an iterative process, with the concept becoming more definitive as available data become more definitive. For the purpose of this discussion, only one iteration will be described, and it will be assumed that operational requirements are firm, and materiel design is preliminary and resulted in part from maintenance engineering requirements based on historical data.

From operational requirements, maintenance engineering knows the manner in which the materiel will be used, the frequency of use, the operational environment, deployment data, availability requirements, etc. From a functional analysis of the design, maintenance significant items, feasible hardware packaging, fault detection and fault isolation methods, accessibility, etc., are determined. With this information, maintenance engineering accomplishes a support synthesis that provides for systematic selection of a cost-effective maintenance concept and identifies new design requirements.

Support synthesis examines and describes feasible support subsystem approaches. Synthesis is defined as the combination of parts or elements so as to form a whole. In this case, it is the combination of various support approaches into a support subsystem. Synthesis forces consideration of support alternatives that might otherwise be overlooked.

A wide variety of support approaches must be considered while materiel is in the preliminary design stage. Support subsystem synthesis evolves from combinations of such considerations as test equipment automation; external or built-in test equipment; number and location of built-in test points; use of automatic, semiautomatic, or manual fault detection; on-line or off-line maintenance actions; on-equipment or off-equipment repairs; replacement units or piece parts; subassembly or assembly; time change or replacement at failure; degree of modularization to be used; system packaging for accessibility; personnel skill mixes; maintenance allocations; and stock levels. Evaluation of these approaches is a complex problem because of the permutations involved. An aid in documenting synthesis efforts is the maintenance profile discussed in par. **4-1.3.**

There are three problems that must be solved in synthesizing a subsystem:

a. The variables representing the subsystem must meet the purpose of the investigation. Synthesis may sometimes take specialized forms such as describing the subsystem in terms of apportioned downtime, as in operational availability studies; or in terms of cost elements, as when life cycle costing studies are being made.

b. The scope of the representation must be adequate. Care must be taken not to oversimplify because often the worth of many of the maintenance design approaches is realized only when these approaches are combined with other features.

c. Care must be taken in describing the synthesized support subsystem. Since these alternatives are the focal point of the support decisions, the language in which alternative actions are described can strongly influence the final solution. All characteristics of the approaches should be made known and quantitatively described.

4-1.3 MAINTENANCE PROFILE

A maintenance profile is a tabular representation of feasible maintenance concepts for a system function or hardware component. It presents the decision parameters of possible alternate concepts in a manner that complements modeling or other evaluation efforts. A maintenance profile has two basic purposes: first, it is a worksheet aid in initial identification of maintenance functions and in presenting all possible methods for their accomplishment; second, once drawn up, it is the communication medium for presenting maintenance alternatives for evaluation.

A maintenance profile is used as a means of synthesizing approaches for accomplishing the maintenance functions. These approaches, once evaluated and decisions made as to the most desirable, form the basis of the maintenance concept that will be implemented for the system and its component equipment. The decision matrices contained in the maintenance profiles must be developed prior to the establishment of any firm hardware configurations. This necessitates their use early in the maintenance engineering effort, and generally before significant maintenance engineering analysis data records can be completed. Because the profiles involve decisions concerning modularization, test equipment, and test point locations, it is important that such requirements be determined early enough to become design features of the system.

The value of a maintenance profile is its presentation of alternate maintenance approaches for an item. The way these alternatives are entered may vary to suit the individual evaluation effort. In most cases, when the choice is between ways of accomplishing a maintenance function, such as built-in automatic fault isolation versus manual troubleshooting, the maintenance function is repeated for each alternate method of performing it. In other cases, when the alternatives affect several maintenance functions, such as disposable versus repairable modules, it may be more advantageous to repeat the complete set of maintenance functions for each maintenance concept.

Maintenance profile worksheet entries are those required to portray adequately the possible maintenance approaches to be considered for the system. The entries shown in Fig. 4-1 are typical. Entries should be those that are most meaningful to the design engineering/maintenance engineering/modeling triad that must coordinate decisions on the proposed maintenance design. Fig. **4-1** entries are:

a. Group Code. List the hardware indenture code of the item for which the maintenance profile is being developed. Ideally, this code will be the same as the code used for the maintenance engineering data system.

b. Nomenclature. Enter the name of the item or performance function.

c. Failure Rate λ. Show the average failure rate for the item or function named. The failure rate is an important basis for decision no matter what the maintenance approach, and it is desirable that it be included. It may be desirable to give the minimum and maximum range of values within which the failure rate may fall to provide a basis for parametric analysis. If a maintenance factor (operational failure rate) is already known, use this value.

d. Maintenance Function. List the maintenance functions applicable to the item. In addition to the functions generally addressed in the maintenance allocation charts, add the functions of fault detection and fault isolation.

e. Equipment Status. State the condition of the end item during performance of the maintenance function (power on and working, system in standby, system down, etc.). This is important to evaluate the effect upon system availability.

f. Performed When. Enter the frequency of the maintenance function. This entry should indicate whether the maintenance is required as a result of a failure (corrective maintenance), or whether the function is to be performed at some interval of calendar, operating time, cycle, or other measure for preventive or periodic functions. Indicate if the function is required in conjunction with or as a result of another function, such as an "align" or "adjust" function being required after a "repair" function.

ITEM ____________________ **MAINTENANCE PROFILE NO.** __________

GROUP CODE	NOMEN-CLATURE	λ			MAIM. FUNCTION	EQUIP. STATUS	PERFORMED WHEN	PERFORMED AT	PERFORMED BY	TMDE		PERSONNEL		MAINT. TIME	REMARKS
		MIN	AVG	MAX						TYPE	LOCATION	QTY	SKILL		

Figure 4-1. Maintenance Profile Worksheet

g. Performed At. Show the maintenance level at which the function is to be performed. In many cases, the maintenance level will be one of the parameters of alternate concepts being depicted on the maintenance profile. If a maintenance concept reflects some variation from the normal Army maintenance organizational structure, it should be indicated for evaluation and fully explained in the "Remarks" column.

h. Performed By. In some cases it may be desirable to indicate the allocation of a maintenance task to man, machine, or a combination that is reflected in a certain maintenance concept. This is needed particularly when various approaches to built-in test equipment, digital techniques, detached automated equipment, and manual methods are being evaluated.

i. Test, Measurement, and Diagnostic Equipment (TMDE). Indicate the extent of test, measurement, and diagnostic equipment involvement in accomplishing the maintenance function. The types of equipment envisioned (manual, semiautomatic, or fully automatic) should be indicated if appropriate for evaluation purposes, as well as whether the equipment will be located on or off the end item. Additionally, indicate if the function is to be accomplished by test equipment located at a higher or lower individual level of hardware. An example of this is a navigational computer whose built-in test equipment can isolate a fault to a plug-in repairable module. The maintenance profile entries against the module would indicate that although the fault detection method is automatic, it would be accomplished by equipment associated with a higher level assembly and actually would require no test equipment for the module itself.

j. Personnel. Enter the quantity and skill level of personnel required to perform the function. If exact MOS requirements are not known, the skills should be displayed in some manner to convey the degree of skill involved in performing the function. For example, a fault isolation function performed manually may require a maximum skill level of **4** on a relative skill scale of 1 to **4**, whereas the same function performed under a concept involving built-in test equipment would require a skill level of **2** on the same scale.

k. Maintenance Time. Indicate the predicted times to perform the function. These data are required to provide availability and cost implications.

l. Remarks. Enter remarks applicable to any of the entries or to the maintenance concept that would assist in the evaluation. If a separate remarks sheet is used, the comments on the separate sheet should be coded and referred to in the "Remarks" column on the profile worksheet. Remarks are an important part of a maintenance profile, because the worksheet entries are only a synoptic outline of the maintenance concept and often do not portray the complete information required for full evaluation of the logistic impact of the concept. Special cost information, special weight and cube data, calibration considerations associated with a built-in test equipment concept, or some variation of standard Army maintenance procedures, such as decentralized direct support, are the types of information that should be included in the additional remarks. In addition, specific information concerning the type of test, measurement, and diagnostic equipment under consideration should be disclosed. For example, commonality of a single piece of test equipment to several areas of system hardware, performance of a maintenance function by a mission related piece of equipment, or hybrid combinations of built-in and multipurpose test equipment should be explained fully to evaluate the maintenance concept.

A maintenance profile can be designed to include all support resources. Facility, technical publications, and repair part requirements can and frequently should be considered, along with the resources shown in Fig. **4-1,** depending upon the materiel being evaluated. In any event, once the profile is complete, all candidates are reverified for compliance with operational requirements. **As** many of the surviving candidates as possible are then eliminated by inspection or top level analysis. Life cycle costs are calculated for the final group, and a maintenance concept selection is made.

4-2 MAINTENANCE PARAMETERS

Maintenance parameters have been identified as qualitative and quantitative maintainability and reliability design features that impact support requirements. These parameters have three major uses. They provide a vocabulary for discussing materiel design, the quantitative parameters provide inputs for trade-offs and models, and both qualitative and quantitative parameters are useful in writing specifications.

Qualitative maintenance parameters other than specification statements are covered adequately in other portions of this handbook (Ref. Tables 3-1 and 6-10). Therefore, the discussion that follows will be limited to definitions of quantitative maintenance parameters and the use of both qualitative and quantitative parameters in materiel specifications.

4-2.1 QUANTITATIVE MAINTENANCE PARAMETERS (Refs. 2, 3)

Many of the quantitative maintenance parameters are based on elements of maintenance time. A discussion of these time elements and of several quantitative maintenance parameters follows.

4-2.1.1 Materiel Life Cycle Time Elements

After it is produced and deployed, materiel can be mission ready, down for maintenance, or in storage or reserve. Fig. 4-2 shows these states as time elements, and particularly delineates between preventive maintenance activities, which can be scheduled, and corrective

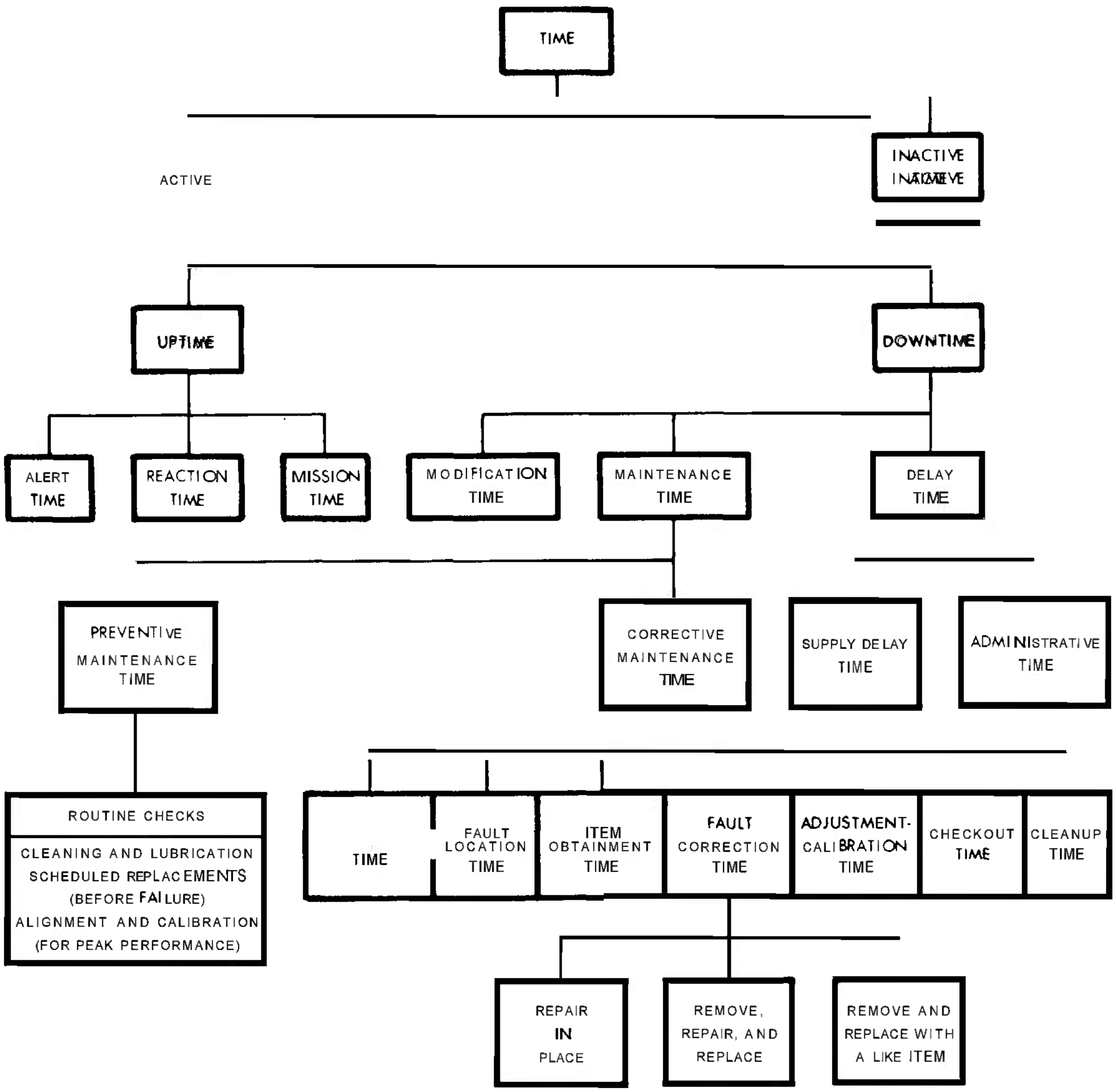


Figure 4-2. Materiel Life Cycle Time Elements (Ref. 4)

maintenance activities, which occur randomly in time.

Many of the elements in Fig. 4-2 are self-explanatory. The others will be defined.

a. Inactive time is that time during which materiel is in the inactive inventory (storage or reserve). This time does not enter into maintenance parameter considerations.

b. Modification time results in downtime and unavailability of materiel. It is placed in a special category, because there is no way other than by extrapolation from historical data to estimate the quantity and nature of required modifications.

c. Supply delay time is the time spent in obtaining repair'parts from other than an organizational stockroom.

d. Administrative time comprises all elements of delay time except supply delay time. For example, travel time by maintenance personnel is an administrative delay.

4-2.1.2 Mean lime Between'Failures *MTBF*

MTBF is a fundamental quantitative maintenance parameter. This parameter establishes the frequency at which corrective maintenance is performed.

MTBF is derived for a particular interval by dividing 'the total functioning life of a population of an item by the total number of failures within the population during the measurement interval. The definition holds for time, cycles, miles, events, or other measures of life units (Ref. 4). For example, if a population of items compiled a functioning life of 100,000 hr and incurred 500 failures in a measurement interval,

$$MTBF = \frac{100{,}000 \text{ hr}}{500 \text{ failures}}$$

$$= 200 \text{ hr per failure} \qquad (4\text{-}1)$$

There is a mathematical relationship between the *MTBF* and failure rate λ for materiel. Failure rate is the number of failures of an item per unit measure of life (time, cycles, miles, events, etc., as applicable to the item) (Ref. 4). Using the values in Eq. 4-1,

$$\lambda = \frac{500 \text{ failures}}{100{,}000 \text{ hr}}$$

$$= 0.005 \text{ failure per hr} \qquad (4\text{-}2)$$

Eq. 4-2 is the reciprocal of Eq 4-1. Therefore, when either *MTBF* or λ is known, the other may be determined by applying the mathematical expression

$$MTBF = 1/\lambda \qquad (4\text{-}3)$$

Maintenance engineering should be familiar with several terms applicable to *MTBF.* Background information and definitions of the terms are given in paragraphs that follow.

Development and operational tests conducted to determine materiel compliance with specifications are relatively limited in number due to economic and schedule considerations and may not reflect the true *MTBF* of materiel. Therefore, procurement decisions based on test results include an element of risk to both the Army and contractor; to the Army because inadequate equipment may be accepted, and to the contractor because adequate equipment may be rejected. MIL-STD-781B (Ref. **6)** describes test procedures that provide an equitable spread of Army and contractor risks. Several terms used and defined in the military standard that maintenance engineers may encounter during a materiel acquisition program are:

a. Minimum acceptable *MTBR* A value ***so*** selected that an associated and specified risk of accepting the equipment is tolerable. This value is associated with consumer (Army) risk.

b. Specified *MTBR* The *MTBF* value **spec**ified in the Contract or equipment specification. This value is associated with producer (contractor) risk.

c. Discrimination ratio: The ratio of the specified *MTBF* to the minimum acceptable *MTBF.*

d. Consumer's decision risk: The probability of accepting equipment with a true *MTBF* equal to the minimum acceptable *MTBF* (the. probability of accepting equipment with a true *MTBF* less than the minimum acceptable *MTBF* will be less than the consumer's decision risk).

e. Producer's decision risk: The probability of rejecting equipment with a true *MTBF* equal to the specified *MTBF* (the probability of rejecting equipment with a true *MTBF* greater than the specified *MTBF* will be less than the producer's decision risk).

MIL-STD-781B assigns standard symbols to the foregoing terms and provides considerable information on reliability tests which is beyond the scope of this discussion. The document should be consulted before an attempt is made to use or evaluate the results of tests conducted under its provisions.

4-2.1.3 Individual Corrective Maintenance Task Time M_{ct_i}

M_{ct_i} is the time required to complete an individual maintenance task or an individual maintenance action. Individual' maintenance task or maintenance action times observed during a test, for example, would be denoted as M_{ct_i}. When maintenance time estimates are based on an average of several observations, as used in prediction analysis for example, individual maintenance task or action times are denoted by M_{ct_i}, to indicate that the value is an average value for the individual task or action. The following notations for individual corrective maintenance time are used throughout and are interchangeable in the equations in which they appear:

M_{ct_i} = corrective maintenance time required to complete the ith individual maintenance task or the *i*th individual maintenance action, based on a single observation.

$$\overline{M}_{ct_i} = \frac{\sum_{i=1}^{N} M_{ct_i}}{N} \qquad (4\text{-}4)$$

= average corrective maintenance time required to complete the ith individual maintenance task or the ith individual maintenance action, averaged over several (e.g., *N*) observations for the same (ith) task or action.

$\overline{M}_{ct_i}$ is synonymous with M_{ct_i} when $N = 1$, as in the case of single observations for individual maintenance actions completed during a demonstration test.

4-2.1.4 Mean Time To Repair $\overline{M}_{ct}$

$\overline{M}_{ct}$ is the mean time required to complete a maintenance action; i.e., total maintenance downtime divided by total maintenance actions, over a given period of time. Mean time to repair (often denoted as *MTTR)* is defined as the summation of all mintenance downtime during a given period divided by the number of maintenance tasks (actions) during the same period of time, given as:

$$\overline{M}_{ct} = \frac{\sum_{i=1}^{N} \lambda_i \overline{M}_{ct_i}}{\sum_{i=1}^{N} \text{Xi}} \qquad (4\text{-}5)$$

where

λ_i = failure rate of the individual (ith) element of the item for which maintainability is to be determined, adjusted for duty cycle, catastrophic failures, tolerance and interaction failures, etc., which will result in deterioration of item performance to the point that a maintenance action will be initiated.

$\overline{M}_{ct_i}$ = average repair time required to correct the ith repairable element in the event of its failure.

4-2.1.5 Median Time To Repair $\widetilde{M}_{ct}$

$\widetilde{M}_{ct}$ is the downtime within which 50 percent of all maintenance actions can be completed. The median maintenance downtime is that value which divides all the downtime values so that one-half of the values is equal to or less than the median and one-half of the values is equal to or—greater than the median. The median value M_{ct} also is referred to as the geometric mean $MTTR_G$ or equipment repair time *ERT* in some maintainability documents. The median value of the maintainability function is related to individual time to repair estimates as follows, for the lognormal maintainability function:

$$\tilde{M}_{ct} = \text{antilog}\{\overline{\log M_{ct}}\}$$

$$= \text{antilog} \left\{ \frac{\sum_{i=1}^{N} \lambda_i \log \overline{M}_{ct_i}}{\sum_{i=1}^{N} \lambda_i} \right\} \quad (4\text{-}6)$$

4-2.1.6 Maximum Time To Repair $M_{max_{ct}}$

$M_{max_{ct}}$ is the maximum time required to complete a specified percentage of all maintenance action, often abbreviated as *MaxTTR*. This is a maximum maintenance downtime defined as that value of maintenance downtime below which a specified percent of all maintenance actions can be expected to be completed. Unless otherwise specified, this value is taken at the 95th percentile point of the distribution of downtimes. $M_{max_{ct}}$ is related to individual repair times comprising the underlying lognormal probability density function, as follows:

$$M_{max_{ct}} = \text{antilog}\{\overline{\log M_{ct}} + xS_{\log \overline{M}_{ct}}\} \quad (4\text{-}7)$$

where

$$\overline{\log M_{ct}} = \frac{\sum_{i=1}^{N} \lambda_i \log \overline{M}_{ct_i}}{\sum_{i=1}^{N} \lambda_i}$$

= mean of logarithms of $\overline{M}_{ct_i}$

x = value from table of normal distribution one-tailed test corresponding to the specified percentage point at which $M_{max_{ct}}$ is defined; e.g.,

x = 1.645 for the 95th percentile

x = **1.283** for the 90th percentile

$$S_{\log \overline{M}_{ct}} = \frac{\sum_{i=1}^{N} (\log \overline{M}_{ct_i})^2 - (\sum_{i=1}^{N} \log \overline{M}_{ct_i})^2/N}{N-1}$$

= standard deviation of the ***sample*** of logarithms of average repair times $\overline{M}_{ct_i}$.

4-2.1.7 Mean Preventive Maintenance Time $\overline{M}_{pt}$

$\overline{M}_{pt}$ is the mean (or average) equipment downtime required to perform scheduled preventive maintenance on the item, excluding any preventive maintenance time expended on the equipment during operation and excluding administrative and logistic downtime. Mean time for preventive maintenance is given by:

$$\overline{M}_{pt} = \frac{\sum_{i=1}^{N} f_i \overline{M}_{pt_i}}{\sum_{i=1}^{N} f_i} \quad (4\text{-}8)$$

where

f_i = frequency of individual (ith) preventive maintenance action in actions per operating hour adjusted for equipment duty cycle

$\overline{M}_{pt_i}$ = average time required for ith preventive maintenance action

4-2.1.8 Median Preventive Maintenance Time $\tilde{M}_{pt}$

The equipment downtime required to perform 50 percent of all scheduled preventive maintenance actions on the equipment under the conditions described for $\tilde{M}_{pt}$ is given by the following expression for the lognormal case:

$$\tilde{M}_{pt} = \text{antilog} \left\{ \frac{\sum_{i=1}^{N} \lambda_i \log \overline{M}_{pt_i}}{\sum_{i=1}^{N} \lambda_i} \right\} \quad (4\text{-}9)$$

4-2.1.9 Maximum Preventive Maintenance Time $M_{max_{pt}}$

The maximum equipment downtime required to complete X percent of all scheduled preventive maintenance actions on the equipment is given by the following expression for the lognormal case:

$$M_{max_{pt}} = \text{antilog}\left\{\overline{\log M_{pt}} + xS_{\log \overline{M}_{pt}}\right\} \quad (4\text{-}10)$$

4-2.1.10 Maintenance Downtime Rate $\overline{MDT}$

The maintenance downtime rate per operating hour is comprised of downtime due to corrective maintenance and downtime required for preventive maintenance, given by the following expressions:

a. Corrective downtime rate $\overline{MDT}_{ct}$ is corrective maintenance downtime per hour of operation, given by:

$$\overline{MDT}_{ct} = \sum_{i=1}^{N} \lambda_i \overline{M}_{ct_i} = \sum_{i=1}^{N} \lambda_i \overline{M}_{ct} \quad (4\text{-}11)$$

where

λ_i = failure rate per hour for the ith item.

b. Preventive downtime rate $\overline{MDT}_{pt}$ is preventive maintenance downtime per hour of operation, given by:

$$\overline{MDT}_{pt} = \sum_{i=1}^{N} f_i \overline{M}_{pt_i} = \sum_{i=1}^{N} f_i \overline{M}_{pt} \quad (4\text{-}12)$$

where

f_i = frequency of the ith task per hour

c. Total downtime rate $\overline{MDT}$ is total maintenance downtime for corrective and preventive maintenance rates combined, given by:

$$\overline{MDT} = \overline{MDT}_{ct} + \overline{MDT}_{pt} \quad (4\text{-}13)$$

4-2.1.11 Maintenance Man-hour per Operating Hour Requirements (Maintainability Index)

Maintainability characteristics of equipment design are reflected in the cost of equipment ownership by the number of man-hours of technician time required to keep the equipment at the specified level of performance. The computation of maintenance man-hours per operating hour (maintainability index) includes the determination of maintenance man-hours required at each of the three levels of maintenance (organizational, field, and depot) per hour of equipment operation. Basic equations for the computation of maintainability indices for a given design are:

a. Maintainability index for corrective maintenance MI_c is the mean corrective maintenance man-hours per equipment operating hour, given by:

$$MI_c = \sum_{i=1}^{N} \lambda_i \overline{M}_{c_i} \quad (4\text{-}14)$$

where

MI_c = mean corrective maintenance man-hours at the designated level of maintenance required per hour of equipment operation

λ_i = failure rate of the individual (ith) repairable element in failures per 10^6 hr of operation, weighted by duty cycle, tolerance, and interaction malfunction rate

$\overline{M}_{c_i}$ = average maintenance man-hours at the designated level of maintenance required to complete the individual (ith) corrective repair action

b. Maintainability index for preventive maintenance MI_p is the mean preventive maintenance man-hours per equipment operating hour, given by:

$$MI_p = \sum_{i=1}^{N} f_i \overline{M}_{p_i} \quad (4\text{-}15)$$

where

MI_p = mean preventive maintenance man-hours at the designated level of maintenance required per hour of equipment operation

f_i = frequency of the ith preventive maintenance action, in actions per 10^6 hr of operation, weighted for duty cycle

$\overline{M}_{p_i}$ = average maintenance man-hours at the designated level of maintenance required to complete the ith preventive repair action

c. Maintainability index MI is a measure of the total maintenance man-hours required to maintain a product in operational status per hour of operation, given by:

$$MI = MI_c + MI_p = \sum_{a=1}^{N} \lambda_i \overline{M}_{c_i} + \sum_{i=1}^{N} f_i \overline{M}_{p_i} \quad (4\text{-}16)$$

d. Maintenance man-hours per task is the relationship between maintenance man-hours per operating hour and maintenance man-hours per maintenance task, given by:

$$\overline{M}_c = \sum_{i=1}^{N} \lambda_i MI_c \quad (4\text{-}17)$$

and

$$\overline{M}_p = \sum_{i=1}^{N} f_i MI_p \quad (4\text{-}18)$$

where

$\overline{M}_c$ = mean corrective maintenance man-hours per corrective maintenance action

$\overline{M}_p$ = mean preventive maintenance man-hours per preventive maintenance action

4-2.1.1 2 Availability

Availability is an operational parameter, but it is defined completely by maintenance parameters. Therefore, definitions and mathematical expressions for the three categories of availability are relevant to a discussion of maintenance parameters.

a. Inherent availability A_i is the probability that materiel, when used under stated conditions in an ideal support environment (e.g., available tools, spares, manpower), will operate satisfactorily at a given point in time. It excludes preventive maintenance actions, supply time, and administrative downtime.

$$Ai = \frac{MTBF}{MTBF + \overline{M}_{ct}} \quad (4\text{-}19)$$

where terms are as previously defined.

b. Achieved availability A_a is the probability that materiel, when used under stated conditions in an ideal support environment (e.g., available tools, spares, manpower), will operate satisfactorily at a given point in time. It excludes supply time and administrative downtime. Achieved availability is directly relatable to the early design process as a means of measuring equipment reliability and maintainability characteristics.

$$A_a = \frac{MTBM}{MTBM + \overline{M}} \quad (4\text{-}20)$$

where

$MTBM$ = mean time between all maintenance, corrective and preventive. Corrective maintenance requirements are determined by inherent reliability modified by K-factors for manufacturing defects, operator errors, etc.

$\overline{M}$ = mean maintenance time for both corrective and preventive tasks.

A mathematical expression for $MTBM$ is:

$$MTBM = \frac{1}{\dfrac{1}{MTBM_{ct}} + \dfrac{1}{MTBM_{pt}}} \quad (4\text{-}21)$$

where

$MTBM_{ct}$ = mean time between corrective maintenance

$MTBM_{pt}$ = mean time between preventive maintenance

A mathematical expression for $\overline{M}$ is:

$$\overline{M} = \frac{(\overline{M}_{ct})\dfrac{1}{MTBM_{ct}} + (\overline{M}_{pt})\dfrac{1}{MTBM_{pt}}}{\dfrac{1}{MTBM_{ct}} + \dfrac{1}{MTBM_{pt}}} \quad (4\text{-}22)$$

where terms are as previously defined.

c. Operational availability A_o is the probability that materiel, when used under stated conditions in an actual operational environment, will operate satisfactorily when called upon. A mathematical expression for continuously operating materiel is:

$$A_o = \frac{MTBM}{MTBM + MDT} \quad (4\text{-}23)$$

where

MTBM is as previously defined

MDT = mean downtime. This is the total time during which materiel is not ready to perform its intended function, and includes all downtime shown in Fig. 4-2, except modification time.

Operational availability for a system that does not operate continuously, but is used intermittently, or is operated for a short period of time for checkout, and is then considered available can best be expressed by:

$$A_o = \frac{MTBM + \text{ready time}}{MTBM + \text{ready time} + MDT} \quad (4\text{-}24)$$

where

MTBM and *MDT* are as previously defined

Ready time = time when materiel is ready for use, but is not actually being operated

In addition, operational availability may be defined and calculated by the following expression:

$$A_o = \frac{U_t}{U_t + D_t} \quad (4\text{-}25)$$

where

A_o = operational availability

U_t = uptime, the time that materiel is mission ready

D_t = downtime, the time that materiel is not mission ready

Uptime U_t is that time during which maintenance is not performed and materiel is ready for use. Downtime D_t is all of the downtime shown in Fig. 4-2, except modification time.

4-2.2 MAINTENANCE PARAMETERS IN SPECIFICATIONS

The incorporation of maintenance parameter requirements into materiel specifications is equal in importance to determining what the parameters should be. To be of greatest use, the parameter requirements must be properly worded. If satisfaction of the requirement cannot be verified by test or demonstration, the value of the specification entry is lessened. In writing specifications, eliminate, whenever possible, the use of such vague wording as minimize and maximize. The specification should contain the following:

a. Definitive statements with no ambiguity

b. Realistic quantitative and qualitative requirements consistent with the state of the art and materiel constraints

c. Requirements that can be tested or demonstrated.

Unfortunately, it is not possible always to write quantitative specifications for complex materiel programs in the early program phases. The knowledge with which to write some of the desired specifics does not become available until well into the development phase. In these cases, it is necessary at times to write qualitative statements. To demonstrate this, some randomly selected system specification requirements for an Army system currently in development will be given. It will be noted that the requirements reflect a mixture of qualitative and quantitative parameters. These requirements are followed by an assumed list of specification requirements that demonstrate how quantitative parameters information should be used, if it is available.

4-2.2.1 Extracts From a Current Specification

The following extracts from a system specification for an Army system currently in development have been edited to such a minor degree that they may be considered as direct quotations. Quantitative requirements pertaining to maintenance times are included in the specification, but are classified and not included here.

a. Test Equipment. The system shall be so designed that necessary operator and organization maintenance can be performed by using common and special test equipment. Common test equipment shall be used whenever it is cost-effective to do so. Special tools and test and calibration equipment shall be developed concurrently with development of the end items or system. To preclude any unnecessary introduction of new tools or test and calibration equipment into the supply system, a review shall be made of items in the Department of

Defense inventory to insure that maximum use is made of existing items prior to proceeding with a new development effort. The number, weight, types, kinds, and sizes of tools and test and calibration equipment required for maintenance shall be kept to a minimum. It is desired that organizational test and maintenance equipment be integral to the tactical equipment.

b. Maintenance Calibration and Secondary Transfer Equipment. The required maintenance calibration and secondary transfer calibration equipment shall be developed concurrently. When no existing GFE or acceptable commercial equipment is available, items will be selected, tested, and type classified, if appropriate, as part of the overall system. Maintenance calibration and secondary transfer calibration equipment shall be provided for those items of common and special test equipment used by the system in the field.

c. Accessibility Requirements. System design shall insure ease of accessibility to such frequently checked items as batteries, filters, lubrication points, and replacement items. The test points for system peculiar electrical components shall be accessible from the interior of the shelter to the extent practicable.

d. Electrical Component Replacement. It is required that, when feasible, electrical components requiring field replacement be capable of being removed and replaced from the interior of the shelter.

e. Modular Design. The system shall be designed to make maximum use of integrated circuit subassemblies and modularized subassemblies. Equipment (electrical, hydraulic, and pneumatic) shall be packaged into economically optimized, nonrepairable modules, whenever cost-effective. The number of different types of system modules and components shall be minimized to reduce the number of repair part line items and tool types required for maintenance.

f. Lubrication. The number of points to be lubricated shall be kept to an absolute minimum. All grease fittings shall be of the same type throughout the system and shall accommodate standard Army greasing equipment. Fill ports shall be readily accessible and large enough to facilitate filling, and shall incorporate features to impede the introduction of impurities. They shall be located so that lubricants can be replenished conveniently.

g. Alignments and Adjustments. Alignments and adjustments shall be reduced to the fewest number possible. All alignments and adjustments, except those associated with maintenance calibration, shall be performed with the use of built-in test equipment. Adjustments and alignments, other than those controls normally available to operator personnel, shall not be required after installation of a unit or assembly by organizational level maintenance personnel.

h. Quantity of Repair Parts. The number of new and common line items in the system shall be minimized.

4.2.2.2 Typical Quantitative Specification Requirements

The typical examples that follow reflect the incorporation of quantitative maintenance parameter requirements into specifications. Each blank space represents a quantity or positive instruction.

a. Maintenance.

(1) Preventive maintenance downtime shall not be more than ____ hours within a ____ day period.

(2) Preventive maintenance shall not be required.

(3) The mean active maintenance time for the materiel shall not exceed ____ hours. This time shall be calculated in the manner prescribed by ____ .

(4) Maintenance reliability, the probability that the materiel is capable of performing its mission after a satisfactory maintenance checkout, shall be greater than ____ percent.

b. Mechanical and Electrical Packaging.

(1) That portion of the materiel that accounts for at least ____ percent of the total failures shall be packaged in disposable modules with a procurement cost goal of $____ , but not to exceed $____ .

(2) The number of different types of plug-in subassemblies shall not exceed ____ .

(3) Hoisting provisions shall be provided on all removable items that weigh more than ____ pounds.

(4) All fastening devices securing access entries shall be captive and hand operated.

(5) All connectors shall be mounted to provide a minimum space of _____ inches between adjacent connectors and other obstructions.

c. Adjustments.

(1) The materiel shall not require periodic field electrical or mechanical adjustment or alignment during its specified service life. Adjustable electrical or mechanical components may be used, provided they are set and sealed at the factory.

(2) There will be no maintenance adjustments on the materiel unless they are justified by total system trade-offs and approved by the procuring agency.

d. Calibration.

(1) The materiel shall require no talibration.

(2) The materiel shall not require calibration in less than a _____ day interval, or after less than _____ operating hours. Required calibration time shall not exceed a mean of _____ hours.

e. Miscellaneous.

(1) The materiel shall be maintained at the _____ maintenance level with standard hand tools. Standard tools are defined as tools that are already in the Federal Supply System.

(2) Each assembly, subassembly, or piece part that is subject to replacement at any maintenance level shall be an interchangeable item. Interchangeable items are those having the same manufacturer's or stock number which, when substituted for each other without modification, selection, or adjustment, shall provide identical physical and functional characteristics.

4-3 MAINTENANCE MODEL

The design and development of a cost-effective materiel-support subsystem combination, also called a weapon system, require concurrent consideration of many variables. There is interdependence between the operating materiel and the support subsystem as a whole, as well as interdependence between various types of resource requirements within the sub-system. Materiel cost-effectiveness is attained by optimizing the many dependent interfaces. When this is accomplished, the result is a materiel-support subsystem combination which imposes minimum life cycle costs. After the materiel is deployed, field data are used as a basis for evaluating and improving materiel cost-effectiveness.

The paragraphs that follow describe a maintenance procedural model that can be used to guide the accomplishment of required optimization actions. Later, the model is applied to a subsystem of a currently deployed Army weapon system.

4-3.1 MAINTENANCE PROCEDURAL MODEL

A maintenance procedural model is depicted in Figs. **4-3** and **4-4.** Fig. **4-3** is a top level functional flow diagram that includes the determination of maintenance requirements and the reporting of field experience. The model shows that some field reports can initiate the total model cycle, while others initiate only part of the cycle.

Fig. **4-4** shows the second level, detailed activities associated with the first seven steps of the top level flow.

To insure continuous harmony between operational materiel and the support subsystem, the model sequence is iterated many'times during a materiel program. This means that at any point, the maintenance concept and support resource requirements are identified to the degree permitted by materiel design definition.

The paragraphs that follow describe activities involved in accomplishing the nine top level steps when the model is'used. Reference to Fig. **4-4** will be useful during discussion of the first seven steps.

4-3.1.1 Step 1.O—Identify Items

Maintenance engineering analysis is performed on each item of the system that contributes to the maintenance burden of the system. These items are identified from a generation breakdown provided by configuration management. The identification may include, but not be limited to, the following: nomenclature, work breakdown structure number, equipment identification code, and drawing: number. The items selected are the maintenance significant items. Analysis also is performed on Government-furnished equipment, if this is a contractual requirement.

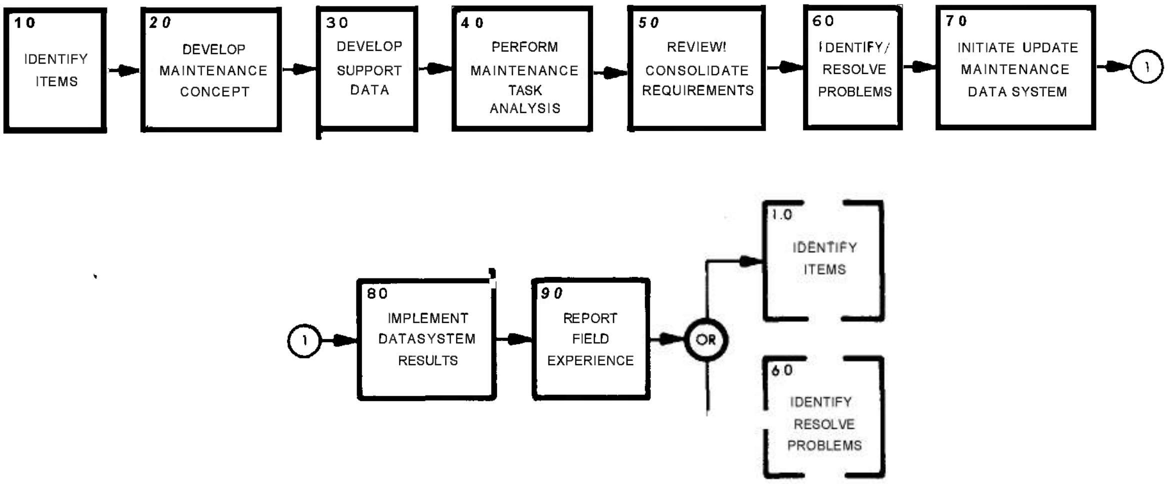


Figure 4-3. Maintenance Procedural Model — Top level

4-3.1.2 Step 2.0—Develop Maintenance Concept

Current data from other functional areas are combined with previously developed maintenance engineering analysis data. These current and previously developed data 'consist of such items as:

a. Design data

b. Preliminary engineering drawings and/or sketches

c. Reliability and maintainability data

d. Maintenance related data for government furnished equipment

e. Results of maintenance support tradeoffs

f. Operational requirements.

Alternative maintenance concepts are synthesized with the assistance of a maintenance profile chart (par 4-1.3). A final maintenance concept selection is made based on life cycle costs, which are relatively gross since detailed resource requirements are not determined at this point in the model. The maintenance concept decision, normally made in conjunction with maintainability engineering, involves the determination of who, where, how, and with what (support resources) materiel will be maintained.

The maintenance concept is constrained by operational requirements. During the formulation of the maintenance concept, maintenance engineering and maintainability engineering maintain close liaison and interchange maintenance analysis and maintainability analysis data. The selected maintenance concept:

a. Provides the practical basis for design, layout, and packaging of the system and its test equipment.

b. Establishes the scope of maintenance responsibility for each maintenance level and identifies the support resources.

4-3.1.3 Step 3.0—Develop Support Data

Maintenance engineering, based on hardware identification, design, performance requirements, and the maintenance concept performs maintenance engineering analysis. The analysis process at this point has progressed from the top level maintenance profile to the detailed analysis of materiel in terms of support requirements and general identification of the required resources. During this process, general types of support resources, such as an unspecified type of multimeter, are selected that satisfy the maintenance requirements at lowest life cycle costs.

In the analysis, if problem areas that dictate changes in design or support are identified, studies are initiated to determine the system impact in terms of cost effectiveness.

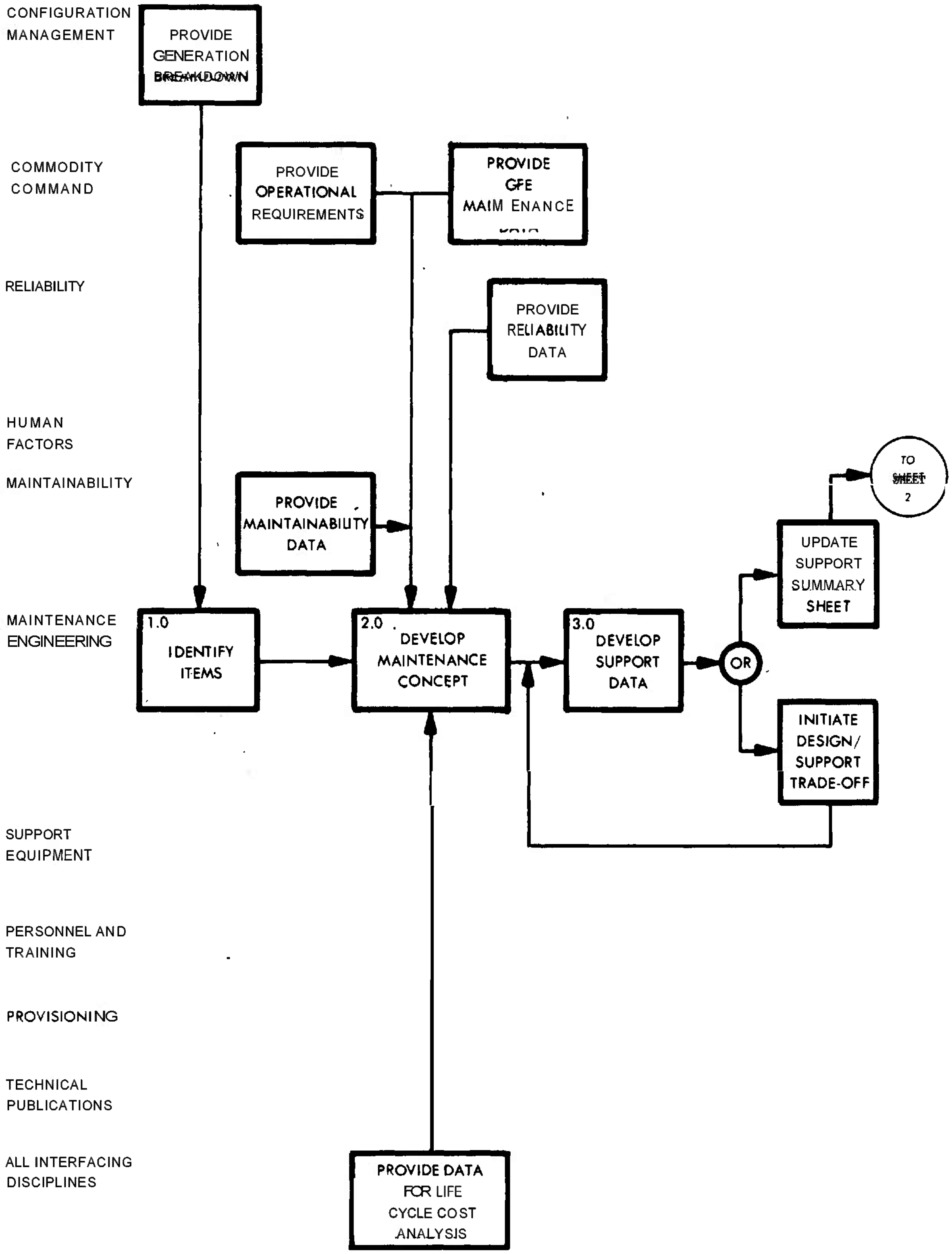


Figure 4-4. Maintenance Procedural Model — Second Level (sheet 1 of 2)

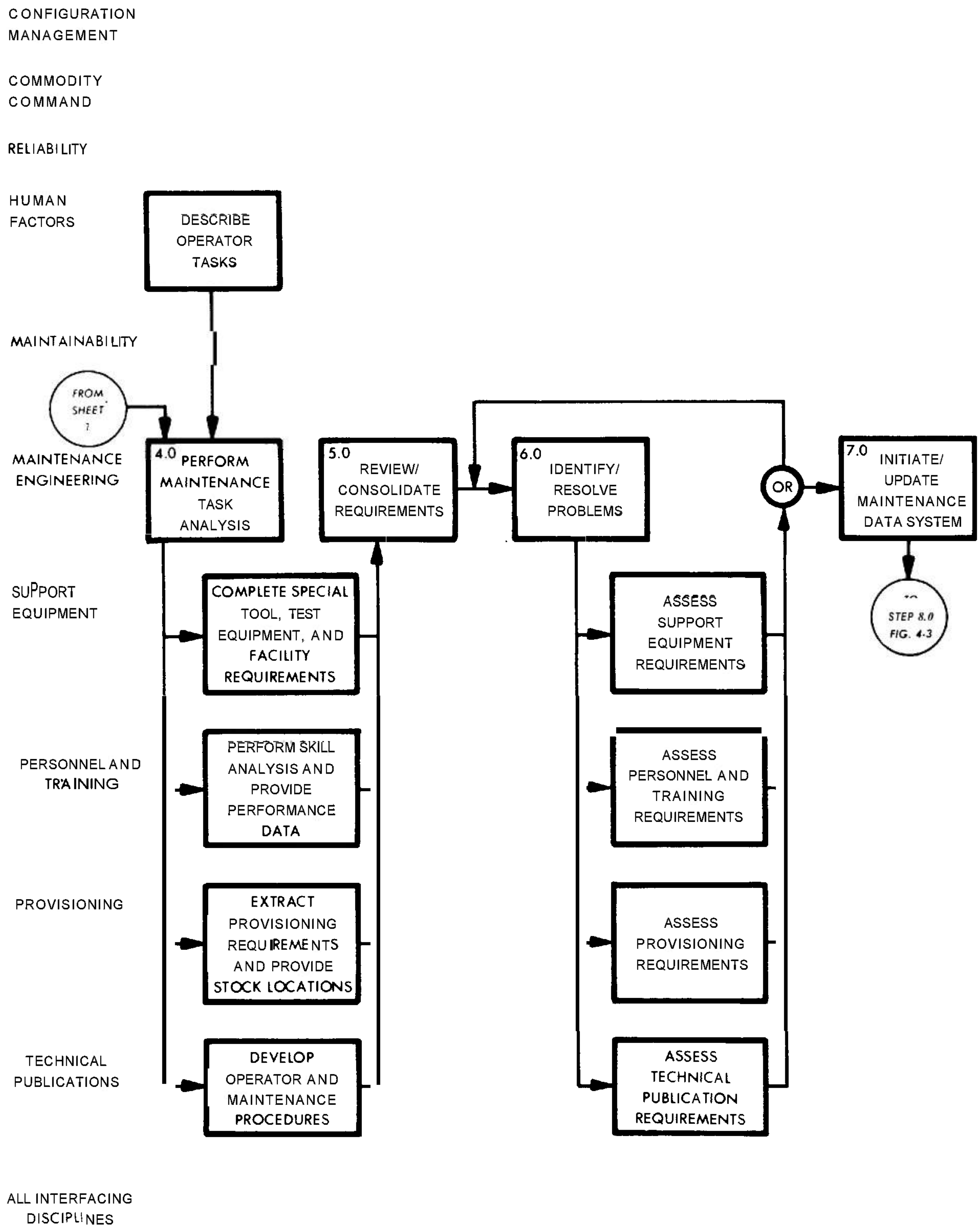


Figure 4-4. Maintenance Procedural Model — Second Level (sheet 2 of 2)

The maintenance analysis is performed for each of the maintenance significant items. The analysis process includes:

a. Identification of the maintenance action and level of maintenance

b. Identification of the maintenance frequency and maintenance factor for each item

c. Identification of the detailed sequential order of performance of the specific tasks to be performed to accomplish the maintenance tasks

d. Identification of the support resource requirements for each item.

The detailed results of the maintenance engineering analysis are entered in the maintenance engineering data system and are summarized for use by other functional areas.

4-3.1.4 Step 4.0—Perform Maintenance Task Analysis

A maintenance task analysis is conducted for each maintenance significant item that requires corrective and/or preventive maintenance. The purpose of the analysis is to describe all maintenance related tasks and specific support resources; i.e., an AN/URM-105 multimeter, required for performance of the maintenance actions in accordance with the mission, the use doctrine, and the maintenance concept. The ultimate goal is identification and documentation of every maintenance task associated with the materiel.

The task analysis begins with delineation of the basic system checkout and maintenance routine. To facilitate this analysis, the checkout and maintenance routine is outlined in flow diagram format to provide a basis for determination and identification of detailed maintenance requirements. The results of the maintenance task analysis include the following data:

a. Facility requirements

b. Tools and test equipment (common and special)

c. Repair parts

d. Consumable materials

e. Refined maintenance factors

f. Sequential maintenance tasks

g. Personnel and skill levels

h. Training requirements

i. Task times

j. Maintenance actions and maintenance levels.

4-3.1.5 Step 5.0—Review/Consolidate Requirements

Upon completion of the individual task analysis for each item, the information developed is summarized on an equipment, an end item, or a system basis. The result of this overall summation will define the overall maintenance and support resource requirements and provides for the consolidation of resources to avoid redundancy.

4-3.1.6 Step 6.0—Identify/Resolve Problems

The results of the task analysis, both individually and overall, are reviewed in relation to maintainability/design requirements, maintenance problems related to design discrepancies, potential logistic support planning revisions, and identification of required design/support trade-offs. These areas are reviewed to assure that the materiel, as designed, and the planned support will satisfy performance and operational requirements at lowest life cycle costs. Each one of the data elements developed during the task analysis is assessed both by maintenance engineering and the support elements. Assessment effort by the support elements is facilitated by the task analysis summaries produced and distributed by maintenance engineering.

4-3.1.7 Step 7.0—Initiate/Update Maintenance Data System

The maintenance analysis data resulting from the foregoing step are entered into the maintenance engineering analysis data system. The maintenance engineering analysis effort is an iterative process, initiated in the concept phase and updated throughout the development, production, and deployment phases. The results of each analysis are disseminated to the support elements. Subsequently, information is received from these elements. The combined information provides a data system package from which information pertaining to a desired hardware level may be extracted.

4-3.1.8 Step 8.0—Implement Data System Results

This step spans the materiel production and deployment phases. During production, maintenance engineering data are updated, and resources identified by the data are acquired. During deployment, materiel is operated and maintained with the procedures and resources that were developed in steps 1.0 through 7.0.

4-3.1.9 Step *9.0*—Report Field Experience

Problems with the materiel are reported on equipment improvement reports or field service reports. These reports provide the basis for identification of changes in design or support, or in operational procedures. Typically, these reports may identify requirements for increased preventive maintenance to prevent problems, changes in operational procedures to avoid hardware failure or personnel injury, and modifications to correct hardware deficiencies. The reported problems may be the result of unusual climatic or environmental conditions not considered in the initial development, or of personnel deficiencies. Whatever the contributing factor, the reported field problems are reviewed by maintenance engineering, and appropriate action is initiated. Serious problems initiate repetition of steps 1.0 through 9.0. Minor problems initiate repetition of all or some of steps **6.0** through 9.0.

4-3.2 MAINTENANCE PROCEDURAL MODEL APPLICATION

In the paragraphs that follow, the model's use and effectiveness of the model is demonstrated by applying it to PERSHING, a deployed Army system. In the interest of simplicity, the discussion is limited to a single end item.

4-3.2.1 Background Information

a. System Description. PERSHING is a surface-to-surface, two-stage, solid propellant ballistic missile with selective range capability. The system provides both a quick reaction alert capability and support for the field Army. The major items of equipment in the system are:

(1) *Programmer-test Station.* The programmer-test station is a mobile fire control center, which consists of the computer and monitoring equipment that automatically perform missile checkout and countdown.

(2) *Erector-launcher.* The erector-launcher consists of a semitrailer transporter, erector, launch pad, a warhead section pallet, and a davit assembly. The erector-launcher provides for transportation, erection, and launching of the missile.

(3) *Power Station.* The power station is a self-contained, skid-mounted unit that produces AC and DC electric power, high-pressure air, and conditioned air. It is powered by a gas turbine engine that uses jet fuel or combat gasoline.

(4) *System Component Test Station.* The system component test station, which is housed in an M373A2 Maintenance Van, performs the rear area PERSHING maintenance mission. The van contains a dismounted programmer-test station, an assembly tester, a pneumatic test console, and a card and module test set. The system component test station provides automatic testing and malfunction diagnostics of items in the PERSHING inventory.

(5) *Power Distribution Sets.* The power distribution sets consist of electrical cables, high-pressure airhoses, conditioned-air ducts, a power distribution box, and an electrical heating control box.

b. Maintenance Philosophy. The PERSHING maintenance concept involves support at each maintenance level, as follows:

(1) Organizational maintenance is performed by and is the responsibility of the using organization on equipment in its possession. Firing battery equipment operators or crewmen and firing battery maintenance personnel perform maintenance that is either preventive or corrective.

(2) Direct support maintenance is performed in support of the using organization by a direct support unit. Direct support maintenance personnel perform corrective maintenance at the firing site or in the rear area. This maintenance includes fault isolation and repair or replacement of components, assemblies, and subassemblies on a return-to-user basis. The direct support units also perform preventive maintenance tasks above the organizational capabilities.

Direct support maintenance personnel use mobile test and maintenance facilities to support the using organization at the firing site.

A system component test station is used in the rear area to diagnose defective items and is augmented by a complete complement of tools, test equipment, and repair facilities with which to perform maintenance. All equipment normally is rendered serviceable and returned to the user through repair or replacement of unserviceable items. When corrective maintenance is beyond the workload capabilities of direct support units, unserviceable items are referred to general support units.

(3) General support maintenance is performed in support of both the user and direct support units in a rear area. This maintenance consists of fault isolation, repair, replacement, and limited overhaul of assemblies and subassemblies beyond the workload capabilities of the direct support units.

(4) Depot maintenance personnel support the Army supply systems through the use of tools and test equipment similar to those of the manufacturer. Repair parts and other materials necessary for repair and overhaul of unserviceable items are stored at the depot. Unserviceable items are restored to a serviceable combat-ready condition and are returned to the supply system, or are salvaged if repair is considered uneconomical. Serviceable items placed in the supply system by the depot shall be functionally and physically interchangeable with and have an operational life expectancy reasonably near that of an identical new item with the same ordnance part or stock number.

c. Problem. Field reports revealed that the PERSHING power station had an unacceptable mean time to repair and an excessive failure rate. The maintenance procedural model (Fig. **4-4**), starting with step **1.0,** was used as guidance in correcting these deficiencies.

4-3.2.2 Step 1.O—Identify Items

The power station items were initially identified from a generation breakdown. The items were identified in terms of group configurations and individual maintenance significant items within the groups. Twenty-nine basic groups were identified. Columns **1** and **2** of the maintenance allocation chart presented in Table **4-1** show some typical groups. Data with which to prepare the maintenance allocation chart, other than group identification, are developed during subsequent step 5.0, and the process is not completed until step **7.0.**

4-3.2.3 Step 2.0—Develop Maintenance Concept

The Army established the following requirements for the redesign and repackaging of the power station:

a. Decrease the existing mean corrective time of 8.6 hr by at least **50** percent.

b. Reduce failures during alert from the existing **15** percent to **6** percent.

c. Design so that **28** percent of the power station failures would be correctable with the power station in its operational position.

The failure rate data are of special significance in this step, for they form the baseline for determining maintenance significant items, the failures anticipated per year, and the maintenance factor for the repair items, and are used in the calculation of the mean time to repair.

It was determined that the mean corrective time reduction would be obtained by increasing accessibility, and the reduction of failures during alert would be obtained by increasing the reliability of the contributing components. The new design was to incorporate the following: redesigned structure enclosure for increased accessibility, a redesigned electrical distribution center to locate centrally electrical components presently located elsewhere, a redesigned control cubicle to swing open for improved accessibility, rerouting of tubing, hoses, and electrical cabling, and relocation of components to increase maintenance accessibility.

Some specific determinations as a result of design analysis were:

a. Turbine. The turbine posed possibly the greatest single power station maintenance problem. In the original unit, work on the turbine and its accessories was accomplished through the top of the power station outer structure. Turbine removal and replacement required **24** hr. It was decided to design the outer power station structure as a "clamshell" attached by quick-release fasteners. Additionally, a coupling was placed in the turbine drive shaft, which permitted removal of the turbine alone. Previously, it was necessary to remove the turbine, a gearbox, and a generator as a unit.

b. Battery ***Access.*** In the original unit, batteries were inaccessible. Adding electrolyte required **2** hr, and battery removal required **2.7**

TABLE 4-1. MAINTENANCE ALLOCATION CHART

(1) GROUP NO	(2) FUNCTIONAL GROUP	(3) MAINTENANCE FUNCTIONS A INSPECT	B TEST	C SERVICE	D ADJUST	E ALIGN	F CALIBRATE	G INSTALL	H REPLACE	I REPAIR	J OVERHAUL	K REBUILD	(4) TOOLS AND EQUIPMENT	(5) REMARKS
	PART I - POWER STATION													
01	Power Station Components	C	C	C	O				O	O			1-B, 1-D, 1-H, 1-I	
02	Cover Assembly and Components													
	Panels	C							F	F				A-A
	Mechanism, Sliding Door				F				F	F				
	Switch, Sensitive				O				O					A-H
	Wiring								O	F				
	Horn, Electric								O	F	.			
	Door Assembly, Sliding								F	F				
	Ducting								F					
	Cover Assembly	C							O	O				
03	Air Conditioner, Frame, and Components													
	Air Conditioner		F	O					F	O	D		2-B	
	Valve, Modulating	F		F					F	F	D			
	Valve, Regulating		F						F	D				
	Valve, Butterfly								F	D				
	Actuator Unit								D	D				
	Water Separator Assembly			O					F	O				B-H
	Cooling Turbines			F					F	D				
	Cooling Chamber	F							F					A-A
	Heat Exchangers			F					F	F				
	Muffler and Plenum	F							F					A-A
04	AC Generator, DC Generators, and Components													
	Generator, AC		H						F	F	D		3-B	D-H, D-I
	Generator, DC		F						F	F	D		4-B, 4-F	E-H, E-I
05	Air Compressor and Components													
	Air Compressor		F	C				F	F	O	D		2-B	F-G, F-H
	Relief Valves								F	D				F-I
	Solenoid Dump Valve								F	D				

hr. It was decided to relocate the batteries and place them on a rollout tray.

*c. **Electrical Distribution Center.*** In the original unit, maintenance access was gained by disconnecting numerous cables and removing the unit from its rack. Removal and replacement required 5 hr. It was decided to provide cable service loops and support rails to permit maintaining the unit without disconnecting cables.

*d. **Fault Isolation.*** In the original unit, lights, meters, etc., were used to indicate malfunctions. Any one of several failures would cause the same indication, and procedures did not adequately describe optimum courses of action. It was decided to add additional indicators and to develop detailed fault isolation procedures.

Based on the requirement for percent of repair to be performed at the site, maintenance time requirements, the planned repackaging and redesign, and gross cost analyses, the maintenance concept shown in column 3 of Table 4-1 was selected. The following symbology used in the subcolumns denotes the lowest maintenance level authorized to perform the maintenance functions:

C—Operator or crew

O—Organizational maintenance

F—Direct support maintenance

H—General support maintenance

D—Depot maintenance

4-3.2.4 Step 3.0—Develop Support Data

Preliminary identification of tool and equipment requirements was completed as shown in column 4 of Table 4-1 for each of the maintenance functions identified in column 3. These items were identified by maintenance category, nomenclature, and tool number. In addition, appropriate remarks pertinent to the maintenance functions were delineated in column 5. Examples of tool selection and remarks are delineated in Tables 4-2 and 4-3. The reference codes in Tables 4-2 and 4-3 are keyed to the codes shown in Table 4-1.

4-3.2.5 Step 4.0—Perform Task Analysis

Fault isolation flows, such as the one shown in Fig. 4-5, were developed to various levels of detail during the program phases. These flows, which were developed to assist in the overall task analysis, also formed unique baseline material for development of the technical manuals. In Fig. 4-5, the number 34 (appearing outside the various blocks) indicates a change in maintenance levels from organizational to field.

Due to the detail of the flows, the identification of support resource and design requirements was rapidly accomplished. For example, Fig. 4-5 shows actions to be taken from the time the voltmeters do not indicate voltage with the engine running until corrective maintenance is accomplished. From this diagram, the following requirements for maintenance resources and actions were determined:

a. Test equipment: multimeter for continuity test

b. Maintenance action: replacement locations for DC generator, batteries, switches, relays, and wiring harness

c. Stock location: relays A16A2K7 and A16A2K18 at organizational level

d. Technical publications: requirement for an operator and organizational maintenance manual and a direct and general support maintenance manual to include removal and replacement procedures for items identified in flow

e. Skill data: basic electrical and mechanical skills required

f. Design features: voltmeter on control panel for monitoring voltage.

4-3.2.6 Step 5.0—Review/Consolidate Requirements

To avoid duplication in the maintenance resource identification, requirements resulting from each of the individual task analyses were reviewed and consolidated (or summarized) to the group level and then to the end item level.

4-3.2.7 Step 6.0—Identify/Resolve Problems

The task analysis flows provided the detail necessary to identify problems in the basic maintenance philosophy, system requirements, and previously identified support resources. These problems were resolved.

4-3.2.8 Step 7.0—Initiate/Update Maintenance Data System

The total maintenance analysis was an iterative process throughout the development of the equipment. Initiation or update of the maintenance analysis data system was generated from various sources of information—primarily from the task analysis and maintenance engineering analysis process. This primary effort was supplemented by various other activities. In reference to the power station, the following additional sources were used in the overall process:

a. *Design Guidelines.* Supplementing the contract specifications, design guidelines were prepared and issued to each engineer. These were specific, detailed requirements based on an allotted time to achieve the proper access and removal of each component and assembly within the power station. Of these requirements, 95 percent were met during the design program.

b. Mock-up. A full-scale wooden and foam mock-up was constructed and used for design reviews and for testing various detailed concepts before documentation. The mock-up proved very effective and enabled the design engineers virtually to eliminate post-release design changes.

c. *Time Line Analysis.* An analysis of the time required for each maintenance action was prepared and continually revised throughout the redesign program to reflect the hardware configuration. This analysis and the functional flow diagrams were used for continual refinement of predictions and for preparation of training aids and support documentation.

TABLE 4-2. SPECIAL TOOL AND SPECIAL TEST EQUIPMENT REQUIREMENTS

REFERENCE CODE	MAINTENANCE CATEGORY	NOMENCLATURE	TOOL NUMBER
1-B	F	:able Resistance Test Set	11039161
	F	Dummy Connector (DC power on)	11054408-9
	F	Electronic Voltmeter	5625-072-4303
	F	Igniter Circuit Tester, Model 101-5BF	4935-712-0205
	F	Load Bank, Sun Electric Model GLB-3A, Modified	MIS17523/1-1
	F	Multimeter, AN/URM-105	6625-999-6282
	F	Oscilloscope	6625-880-1930
1-D	O	Shop Equipment, Organizational Repair, Light Truck Mounted	4940-294-9516
1-H	O	Multiple-leg Sling	11025262
1-I	F	Contact Team Tool Kit; Pershing Missile System	4935-782-1315
	F	Digital Repairman Tool Kit; Pershing Missile System	4935-782-1314
	F	Dummy Connector (top cover inter-lock)	11053122-9
	F	Electrical Shop Tool Kit; Pershing Missile System	4935-782-1313
	O	Firing Position Tool Set; Pershing Missile System	5180-935-4688
	O	Hose Assembly	NAS1690-04-29R4
	F	Mechanical Shop Tool Kit; Pershing Missile System	4935-782-1312
	O	Multiple-leg Sling	11025262
	O	Pressure Gage-Range 0-5,000 psi	6685-840-3747
	O	Reducer	4730-510-7194
	F	Shop Equipment, Contact Maintenance, Truck Mounted	4940-294-9518
	O	Shop Equipment, Electronic Repair, Semi-trailer Mounted	4940-294-9542
2-B	F	Test Set, Pneumatic System Components XM83 (See Section 11, Part II for maintenance functions)	1450-005-4877
3-B	H	Load Bank	6115-964-1091 or equiv.
4-B	F	Dummy Connector (DC power on)	11054408-9
	F	Load Bank, Sun Electric Model GLB-3A Modified	MIS17523/1-1
4-H	F	Switch, SPDT, Momentary, 20 A	5930-655-1521

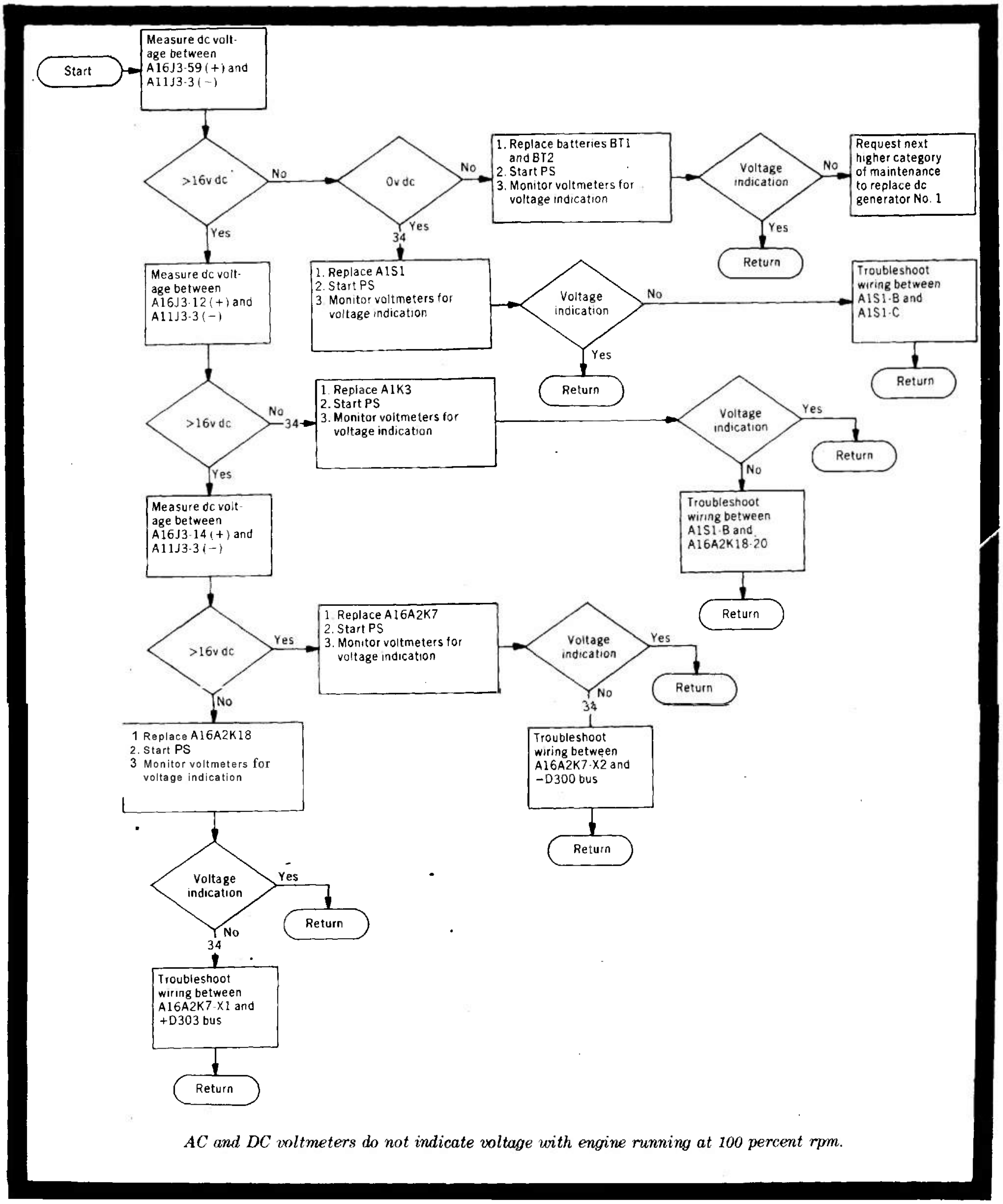
TABLE 4-3. SPECIAL INSTRUCTIONS

REFERENCE CODE	REMARKS
A-A	Visual Inspection.
A-H	Attaching hardware supplied with switch.
B-H	CAUTION: Wear gloves while handling Fiberglas condenser. Avoid stretching condenser out of shape or breaking glass fibers.
C-I	Field repair limited to removing minor dents in ducts and repair of minor cracks by welding.
D-H	Use thin film of grease MIL-G-23827 to lubricate spline before installation.
D-I	Field repair limited to replacement of main cover, terminal boards, capacitor, air inlet, brushes, and associated attaching hardware.
E-H	Prior to installation of generator, flash shunt field in accordance with prescribed procedures. Use thin film of grease MIL-G-23827 to lubricate spline before installation.
E-I	Field repair limited to replacement of terminal blocks, brushes, and brush springs.
F-G	When installing new compressor, use spline coupling from old compressor; and remove shipping plug and install oil dipstick tube and attaching parts from old compressor. Compressor is shipped with plug, P/N 1854-3700 installed over reducer, P/N MS21916-6-4; remove this plug and all shipping plugs and install existing lines and hardware.
F-H	Use thin film of grease MIL-G-23827 to lubricate spline before installing compressor.
F-I	The 3rd stage relief valve cannot be removed until 4th stage head is removed (a depot function).
G-I	Repair limited to straightening and rewelding as required.
H-H	If any part of harness assembly, overtemperature cable assembly or lead and sensor assembly is damaged, replace complete assembly.

d. *Trade-offs.* Trade-off studies were conducted to evaluate design alternatives at each design level. The results of these studies enabled the selection of optimum design characteristics in terms of life cycle costs and ease of maintenance.

e. ***Design Reviews.*** Design reviews of the concept, design, and prototype phases were conducted to evaluate design progress toward fulfillment of the contract requirements. During these reviews, which were conducted by management and staff personnel, each segment of design was examined thoroughly to evaluate its impact on maintenance of the unit.

f. ***Maintainability Demonstration.*** A maintainability demonstration was conducted. The 50 randomly selected maintenance tasks were performed in an overall mean corrective maintenance time of 2.1 hr, in contrast to 8.6



AC and DC voltmeters do not indicate voltage with engine running at 100 percent rpm.

Figure 4-5. Sample Flow Diagram

hr for the original unit and an objective of 3.8 hr for the redesigned unit. Additional benefits of the redesign program included an increase in the percentage of power station malfunctions that could be fixed without removing the unit from its trailer-mounted position of 41 percent, in contrast to 3 percent for the original unit and an objective of 28 percent for the redesigned unit. In addition, the overall *MTBF* of the power station was quadrupled, from 15 hr for the original design to a predicted 65 hr for the redesigned unit. Technical publications were used in the demonstration. These publications incorporated the functional flow diagrams developed for the task analysis process. The system was supported in accordance with the resources identified during this process.

4-3.2.9 Application to Other Materiel

The model may be used in developing the maintenance concept and maintenance resource requirements for any type of Army *materiel. Constraints such as operational requirements and Army policy regarding maintenance levels for a particular type of materiel enter the model at step 2 and appropriately modify subsequent steps. For example, Army policy dictates that, whenever practicable for aircraft maintenance, a single level of support or field maintenance will be established between the organizational and depot levels. Therefore, application of the model to aircraft maintenance will produce a three-level maintenance structure with optimized maintenance activities for each of the three levels. Similar Army guidance exists for all types of Army materiel (Ref. 5), and the model user must be guided by this policy.

4-4 MAINTENANCE SCHEDULES

Maintenance schedules are used to integrate, coordinate, and control the accomplishment of corrective and preventive maintenance at all maintenance levels. The schedules specify when and by whom maintenance will be performed, and designate, when applicable, the source of required materiel and material. Sometimes, materiel is out of action awaiting maintenance, and sometimes it must be removed from action to permit maintenance. It follows that operational schedules and maintenance schedules must be coordinated closely. It should be noted that deferment of maintenance to obtain an immediate increased operational capability should only be used in combat, and even then as a last resort.

It is universally accepted that preventive maintenance is scheduled maintenance, and that corrective maintenance is scheduled at the field and depot levels. It sometimes is forgotten that much of the corrective maintenance at the organizational level also is scheduled. The amount to be scheduled depends upon the maintenance concept of the materiel in question. For example, if an item of materiel with built-in test equipment, modular construction, and on-board repair part modules fails, unscheduled corrective maintenance is probably performed. On the other hand, if the failure cannot be isolated by use of the built-in test equipment, scheduled corrective maintenance is required. Normally, if corrective maintenance cannot be accomplished at the operator level, it must be scheduled, because organizational maintenance personnel have a backlog of work, and priorities must be established. It may be seen that for precision, maintenance should be categorized as preventive and corrective rather than scheduled and unscheduled.

4-4.1 MAINTENANCE PLAN

The maintenance plan is a document that describes the requirements and tasks to be accomplished for achieving, restoring, or maintaining the operational capability of materiel. The maintenance plan is published early in a materiel program and is updated periodically thereafter. It includes each maintenance significant item in either new or off-the-shelf materiel. The maintenance plan, based on the materiel maintenance concept, defines the maintenance resources required and establishes their available-for-issue dates, in addition to allocating the tasks to the appropriate maintenance levels; i.e., organizational, field, or depot. The plan includes the target operational readiness date and specific requirements for personnel, technical publications, facilities, repair parts, special tools, test and support equipment, technical assistance, and related maintenance materials to be used for maintenance support.

The system operational readiness date is the focal point in scheduling the availability of these resources. All initiation of activities or procurement required for maintenance support is scheduled to occur in a time frame preceding this date. While the time span for obtaining the resources must allow a reasonable time for contingencies, it should not be such as to induce unwarranted potential for obsolescence or extensive modification of the resource before its use is required.

The maintenance plan provides guidance to all of the organizational elements involved in maintenance and support of the materiel. In the process of developing the maintenance requirements, allocations, and schedules, maintenance engineering' uses experience gained with the same or similar previously' deployed materiel to its full advantage. Maintenance operations to be performed on any item of materiel are assigned to specific maintenance levels in accordance with the following:

a. The primary mission, character, and mobility of the materiel involved

b. The economical distribution of funds, skills, technical supervisors, tools, shop equipment, rèpair parts, materials, etc.

c. The time available for performing the work.

These operations vary from simple preventive maintenance services performed by the personnel who are using the equipment, to complex repair and rebuild techniques practiced at depot maintenance shops.

From the allocation of maintenance responsibilities, affected organizations develop progressively more detailed schedules for maintenance of each maintenance significant item in order to control the accomplishment of all known tasks in accordance with established priorities. These schedules can be relatively firm for preventive maintenance activities accomplished on a periodic basis, needing adjustment only for variations caused by operational requirements and immediate workloads. Corrective maintenance schedules must be developed on the basis of reliability data, actual or estimated, with anticipated failures prorated over **a** period of time on the basis of the best judgment of materiel maintenance specialists and previous experience. The schedules for organizational level maintenance primarily will concern preventive maintenance and corrective maintenance resulting from periodic tests/inspections and operational failures. Field level maintenance schedules are a combination of preventive maintenance beyond the capability of the organizational level maintenance personnel, and corrective maintenance by repair of designated items. Depot level maintenance schedules primarily are concerned with corrective maintenance by repair of failed items, although overhaul of items removed because of life limitations may be considered preventive.

4-4.2 INTEGRATION OF OPERATIONS AND MAINTENANCE

Organizational, direct, and general support level maintenance activities may impact significantly the tactical capability of an Army field unit. This is particularly true in the case of fixed installations such as missile sites and radar sites. The impact may be to varying degrees as follows:

a. The unit is placed in an inoperative condition during the entire time that the maintenance activity is being performed.

b. Unit operations are interrupted for a brief period while the maintenance activity is being performed.

c. The unit must operate in a degraded performance mode.

d. Unit performance levels are normal, but a specific capability is not available.

Since a specified unit operational readiness level must be maintained and periodically demonstrated, and the purpose of a maintenance system is to meet operational requirements with minimum loss of time due to repairs, scheduling of operations and maintenance activities must be integrated. This necessitates a scheduling and workload control function within the field unit which will provide for management of all the unit's resources in performing those activities required to satisfy the unit's mission requirements. This management is accomplished through centralized scheduling of all maintenance and maintenance related activities that directly impact the unit's tactical capabilities.

Conditions that result in the unit being in a status below full tactical capability require control to the fullest extent. In order to relieve such conditions, the following controls are instituted:

a. The scheduling and workload control element is made totally responsible for scheduling necessary maintenance activities and integrating them with the unit's operational schedule.

b. The schedule must be approved by the unit commander.

c. The approved schedule is directive upon all affected maintenance and support organizations.

d. Deviations from the schedule are limited to only those required as a result of failures within critical equipment, or to those resulting from a change in the unit's tactical status requiring an increase in operational readiness level.

Other maintenance activities, consisting of tasks which do not impact directly the immediate tactical capability of the field unit and which can be performed simultaneously with the execution of tactical requirements, are performed under relaxed control. The detailed scheduling, implementation, and execution of these maintenance activities are the responsibility of the affected maintenance organization. However, these schedules are established so as not to conflict with operational requirements and are coordinated with the scheduling and workload control element. Examples of this type maintenance activity are:

a. Preventive maintenance tasks to be performed on a specific piece of equipment that is either redundant or in standby status

b. System tests that can be performed by the use of redundant equipment

c. Incorporation of field modifications on redundant or inactive equipment.

Normally, the unit's scheduling and workload element schedule these maintenance activities to be accomplished within a given time span, with the maintenance area given the prerogative of establishing the specific date that permits the most effective use of its assigned resources.

The complexity of the scheduling task can be illustrated best by a brief review of typical activities which require maintenance support and which must be considered in scheduling maintenance activities.

a. ***Operational Requirements.*** These requirements provide the basis upon which the field unit develops its operational schedule. In addition to the fundamental,.mission, there are equally demanding requirements to exercise the system and establish that its mission can be fulfilled under varying conditions; e.g., technical proficiency inspections and unit training exercises of various magnitudes and duration. These requirements are consolidated into a master operational schedule by the scheduling and workload control element. As maintenance tasks are defined, they are incorporated into the master schedule, which is revised as necessary to avoid conflicts and promote efficient use of the unit's resources.

b. ***Corrective Maintenance.*** This maintenance is performed to restore materiel to a satisfactory condition by correcting a malfunction that has caused materiel performance to fall below a specified level.

c. ***Preventive Maintenance.*** This maintenance comprises systematic inspection, detection, and correction of incipient failures in materiel before they occur, or before they develop into major defects. Since the basic purpose of a preventive maintenance program is to reduce equipment failures, the scheduling and workload control element schedules, coordinates, monitors, and controls the program for all of the materiel assigned to the field unit. Usually, the magnitude of the preventive maintenance activity, at both the system level—which directly affects the field unit's ability to support tactical requirements—and at the item level is so great that it is imperative that preventive maintenance be closely controlled and monitored to verify that all requirements are executed in a timely manner. Additionally, preventive maintenance schedules first are established as a result of historical data and engineering judgment. A thorough and continuing analysis of preventive maintenance reports may reveal that periods between maintenance can be lengthened, or that maintenance can be eliminated.

d. ***Limited Life Component Replacement.*** This maintenance is governed by the basic interfaces, constraints, and controls applicable to preventive maintenance.

e. Calibration. The calibration of test, measurement, and diagnostic equipment and the periodic proof-loading of handling equipment pose a particular scheduling problem when materiel must be removed from a ready status in order to perform the maintenance.

f. Field Modification Programs. Some modification programs are quite time-consuming and severely impact materiel availability.

g. Product Assurance Tests. These tests are conducted to determine the effects of exposure and aging under deployed conditions. The tests may involve removal and replacement of elements of a deployed system for laboratory analysis at a facility remote from the field unit.

h. Training. New personnel training, cross-training, and individual proficiency training may be required. Any training periods or activities requiring on-equipment instruction must be scheduled so as not to interfere with the activities contained in the unit's master operational schedule.

The unit's operational and maintenance schedule presents all activities to be performed in a given time period that impact its capability to satisfy operational requirements. The duration of the time period will depend upon the complexity of the situation. A complex situation will be assumed in which a combined direct and general support unit is in residence at a missile site. The principles advanced may be tailored to fit any situation.

For the assumed situation, operational and maintenance schedules are prepared to provide long-range, intermediate, and daily visibility. In general, a master schedule would be prepared to cover a 1-yr period, with subschedules prepared for current bimonthly, weekly, and daily periods. These schedules must have the concurrence of the unit's operational and maintenance commands, as well as that of the maintenance-support organizations.

The weekly and daily schedules are updated and modified on a day-to-day basis to reflect the specific requirements and limitations under which the unit is operating. Since the longer range schedules are primarily guides for succeeding equivalent periods, they are not updated during the operating period covered. The bimonthly schedule shows each task to be performed during that interval, identified by type of activity, and placed in the approximate time period during which it will be performed; i.e., the day(s) on which the requirement must be accomplished. A brief description of each activity, including an indication of the priority to be assigned, accompanies each schedule form. Since the purpose of the bimonthly schedule is to provide a planning base for future activities, it is revised only on a monthly basis.

The weekly schedule provides a further refinement in time period allocations for each activity. This form of schedule is used primarily as the initial basis for adjusting the daily schedules due to changes in requirements, deferment of activities that were not accomplished, and extensive activities that were not completed in the allotted time frame. Individual weekly schedules are firmed up on the last working day of the preceding week. These schedules are accompanied by a task-by-task description, with each description related to an activity number noted on the schedule.

The daily schedule identifies the specific time at which each task activity is to begin and the total time allocated for accomplishment. A description of each schedule task is attached to the schedule. The description includes the following types of information: brief descriptive sentence; subsystem(s) that must support the task/activity; and the priority placed on the task/activity. In order to develop an effective schedule, the following information is required:

a. The specific equipment involved in the task

b. The specific time period during which the task must be performed, and an alternate period, if the activity permits

C The total time required to perform the task

d. Indication of the impact on the subsystem

e. The impact on field unit operations

f. The impact if the task is not performed during the period originally specified *g.* Support required from subsystems/activities not directly involved in the task.

Prior to issuance, the schedule must be reviewed to determine that:

a. All known requirements for the period covered have been included

b. Maximum simultaneous scheduling of tasks has been considered to minimize equipment downtime or degraded time

c. Satisfactory time allotments have been established to insure that subsequent activities can be accomplished as scheduled

d. Additional requirements that may have been generated subsequent to initial development of the schedule have been incorporated.

The schedules, particularly those for the daily and weekly periods, must take into account the inability of any maintenance organization to anticipate all tasks, especially those of an emergency nature. Consequently, schedules should not assign 100 percent of the time available to specific tasks, but should leave a portion of the time for quick assignment to emergency jobs or other priority tasks not anticipated at the time of scheduling. In other words, the schedule must have some .flexibility. When the schedule is revised, any tasks not completed in the assigned period must be carried over into the succeeding schedule.

After the schedule is reviewed and approved by the affected operational and maintenance organizations, it is issued as the unit commander's direction and authorization to accomplish the tasks as scheduled.

4-5 MAINTENANCE ORGANIZATIONS (Ref. 5)

The Army materiel maintenance function is a component of the materiel division of the Army Logistic System. Therefore, the Army maintenance structure parallels the overall Army logistic structure. It encompasses the materiel maintenance organization and activities **of** the three major segments of the Army Logistic System. These are the Army Wholesale Logistic System, the Army in the Field Logistic System, and the CONUS Installation Logistic System.

Army wholesale materiel maintenance activities include depot maintenance and National Maintenance Points. CONUS materiel maintenance activities generally are those services provided to installed operating equipment and units, other than deployable units, assigned to or as satellites to CONUS installations. Army in the field materiel maintenance activities generally are concerned with the maintenance operations of the organizational, direct support, and general support maintenance levels. This discussion will be limited to Army in the field materiel maintenance activities and depot maintenance.

4-5.1 ARMY IN THE FIELD MATERIEL MAINTENANCE

The materiel maintenance activities of the Army in the field are those internal to theaters of operations and/or performed by and. in support of the missions of commands and activities deployed in oversea areas or deployable commands and activities in CONUS. Army in the field maintenance activities sustain the operational readiness of the force. They activate and operate the Army in the field portion of the maintenance support system, in accordance with the plans and equipment publications prepared by National Maintenance Points, to maintain in a serviceable condition sufficient materiel to satisfy prescribed operational requirements.

4-5.2 ORGANIZATIONAL MAINTENANCE

Each combat, combat support, and combat service support activity is authorized an organic materiel maintenance element (i.e., crew/operator and maintenance personnel) to perform authorized organizational maintenance operations on equipment assigned to or used by it to accomplish its mission.

Normally, maintenance at this level consists of inspecting, cleaning, servicing, preserving, adjusting, and relatively simple repairs accomplished by removal and replacement of components.

For some equipment (e.g., selected items of medical materiel), all authorized maintenance operations are allocated to the organizational maintenance category. Also, certain using units and other activities, because of the design characteristics or limited distribution of their principal items of equipment, or operational requirements, are authorized an organic capability to perform maintenance operations on all or selected items of their organic equipment which normally would be allocated to the support maintenance levels.

4-5.3 SUPPORT MAINTENANCE

Combat service support units are authorized in the Army force structure to provide direct support and general support maintenance service to the Army in the field. To the maximum extent practicable, these units are functionalized; i.e., organized to perform specialized maintenance tasks on equipment of several commodity groupings.

Within each major level of command, support maintenance units normally are assigned to a support element whose commander has been delegated responsibility for operation of the logistic support structure of the command. Logistic control or materiel management centers, including or supported by automatic data processing facilities, established within appropriate staff sections of these elements or as separate entities, assist these commanders in management of their support maintenance operations.

4-5.3.1 Direct Support Maintenance

Direct support maintenance operations are performed on equipment in the direct support unit area, or, when practical and cost-effective, at the equipment use location. Normal maintenance activities include the following: repair of assemblies and modules by simple piece part removal and' replacement; operation of a direct exchange facility for modules; pollution control system maintenance on internal combustion engines; light structural repairs; and alignment, calibration, and evacuation of unserviceable materiel whose repair is beyond the unit's authorized capability or capacity to parallel or higher maintenance levels, as appropriate.

Direct support units make judicious use of highly mobile contact teams. One-stop service, to the extent practical, is the goal of direct support maintenance. In furtherance of this goal, units serve as the supply system outlet for repair parts required by the using units to perform authorized organizational maintenance tasks. They also maintain operational readiness float stocks to assist in maintaining the requisite degree of materiel readiness in supported units, and serve as the primary reentry point for unserviceable repairable equipment to the local area; e.g., theater supply system. Unserviceable items usually are not held at direct support maintenance unit locations if they are not to be repaired and returned to the user or to direct exchange stock. Evacuation or disposition instructions for items that are not economically repairable at the direct support level normally are provided by the appropriate logistic control or materiel management center.

4-5.3.2 General Support Maintenance

General support maintenance operations primarily are aimed at the repair of end items or modules for return to the local area or theater stocks or in support of the direct exchange program. General support units accomplish maintenance similar to that performed by direct support units, as well as more complex maintenance. For example, general support units have greater module and structural repair capabilities. General support units also collect, classify, and dispose of certain classes of unserviceable or abandoned materiel, operate authorized cannibalization points to augment supply stocks, and evacuate materiel to designated depot maintenance facilities. Normally, general support units operate in shops and are considered movable but not mobile.

Items evacuated from direct support units comprise the greater portion of the general support workload. Unserviceable repairable assets are accumulated at general support maintenance units, pending a repair program scheduled by materiel managers at the appropriate command level in response to the needs of the supply system and direct exchange program and in accordance with the availability of the requisite repair parts and other maintenance resources.

4-5.3.3 Field and Intermediate Support Maintenance

In some cases, the maintenance and supply capabilities of direct and general support units are combined and made the responsibility of a single unit. The single unit is called either field support or intermediate support by the Army, and intermediate support by the other services.

4-5.4 DEPOT MAINTENANCE

Depot maintenance operations support the overall Army inventory management program. They are used as an alternative or a supplement to new procurement as a source of serviceable assets to meet Army materiel requirements. Programs in support of the Army in the field are controlled by national level materiel managers. Oversea commanders assigned depot maintenance missions participate in the formulation of depot maintenance programs for which they are assigned responsibility for executing. Approved depot maintenance programs are executed by designated Army arsenals and depot maintenance facilities, by agreement with other military services, and by contractual arrangements with commercial firms.

Depot maintenance normally consists of materiel overhaul, repairs that exceed the capability of the field army, complex inspections, modifications, and fabrication of items and parts not in the supply system when such fabrication is cost-effective.

4-6 SUPPORT PLANNING

The end product of support planning is a maintenance plan that defines the actions and supporting resources required to maintain materiel in its prescribed state of operational readiness. The operational readiness requirement is of paramount importance, and must be satisfied. After its satisfaction, materiel life cycle costs are of primary importance. Therefore, the purpose of support planning is to develop a maintenance plan that will permit deployed materiel to satisfy operational requirements at lowest life cycle cost.

Support planning is initiated at the start of a materiel acquisition or modification program, and continues throughout the materiel life cycle. The magnitude, scope, and level of detail of the planning effort are tailored to meet the specific situation. The following factors are considered in tailoring the planning for materiel acquisition programs (Ref. 5):

a. Intended use (experimental or operational)

b. Mission essentiality

c. Quantity to be procured and method of acquisition

d. Complexity

e. Initial deployment date and anticipated service life

f. Estimated annual and life cycle costs

g. Availability and suitability of existing resources for materiel support.

With due consideration for the foregoing factors, maintenance engineering conducts or insures that a contractor conducts planning to include:

a. Defining the maintenance tasks to be performed to include:

(1) Developing maintenance standards and associated man-hours, skills, and other resource requirements for the performance of each task

(2) Prescribing or forecasting the frequency of performance of each task

b. Establishing maintenance technical training criteria necessary to assure the availability of the required level of technical competence to maintain the materiel

c. Designing the maintenance support structure required for the performance of the maintenance tasks defined, to include:

(1) Determining the levels of maintenance to be used in support of the materiel

(2) Allocating the required maintenance tasks among these levels

(3) Determining the skills, manpower, and technical requirements for maintenance facilities, tooling, test, measurement, and diagnostic equipment, and other support equipment at each category

(4) Selecting and allocating repair parts to the various levels to which maintenance tasks have been allocated. This includes establishing or obtaining through command channels, as part of the initial provisioning process, final decisions on the coding of repair parts and other support equipment with respect to source, maintenance level, recoverability, and essentiality.

d. Insuring that maintenance float factors or quantitative requirements are established, when applicable, and that these factors and requirements are compatible with the planned operational environment and readiness requirements of the materiel.

Two tools of maintenance planning are repair level analysis and maintenance allocation charts. The culmination of support planning is to determine the total resources required for preventive and corrective maintenance. These subjects are discussed in the paragraphs that follow.

4-6.1 REPAIR LEVEL ANALYSIS

Maintenance and repair level decisions are made on the basis of a detailed review of the operational requirements of the system, the technical characteristics of materiel design, and the economics of support. It is an iterative process conducted throughout the conceptual, development, and production phases. A tentative maintenance allocation is necessary early in the program life cycle to analyze adequately the impact of preliminary design decisions. Constraints imposed by operational requirements may dictate the repair level decisions for certain items on the basis of mobility requirements, availability of resources, etc. Other decisions are made on the basis of optimum logistic cost effectiveness and operational capability. The general decision process must allow rapid identification of those tasks which can be allocated immediately and those which require more detailed analysis.

A systematic screening process must be established to eliminate the obvious discard-at-failure items first, and then analyze the remaining items at increasing levels of detail until each item maintenance and repair level is allocated. The first step in the screening process determines those item repair tasks which are not feasible due to technical or economic reasons, and assigns a disposable code to the items. The next step assigns those item repair tasks which are definitely depot or definitely field level in nature for obvious technical and economic reasons. Allocation of the remainder can be accomplished by comparison of the cost of repair at the depot and intermediate levels and the cost of discard at those levels, basing the decision on lowest life cycle cost.

Since a materiel support plan should be completely compatible with the Army logistic system, the considerations that follow should govern the assignment of repair levels. Normally, repair of an item should not be assigned to depot maintenance unless:

a. The repair is a part of a rebuild or overhaul effort.

b. The required repair is to tolerances beyond the capability of lower level maintenance facilities.

c. The repair requires shop facilities with environmental controls not available at lower echelons.

d. The repair constitutes the most cost-effective method of repair.

When repair responsibility is allocated to the general support maintenance level, care must be exercised to insure that properly skilled personnel and necessary test equipment are available within the units assigned that responsibility. In the allocation of repair responsibilities to maintenance levels below general support, maintenance engineering must assure that such repairs are limited to those which:

a. Are possible without the need of complicated tools and procedures

b. Require only easily operated test, measurement, and diagnostic equipment

c. Do not require complex or critical adjustments or system alignment after accomplishment.

The foregoing categories of repairs requiring adjustment ,or system alignment after accomplishment are deserving of additional comment. For repairs by replacement, normal design policy dictates that the requirement for adjustment or system alignment following substitution of replacement items for defective items be minimized. In those instances when it is known that adjustment or alignment is required following repair by replacement, the repair responsibility must be allocated to the maintenance level where the skills and test equipment are available to perform also the adjustment and alignment functions required.

4-6.2 MAINTENANCE ALLOCATION CHARTS

A maintenance allocation chart is a listing of maintenance operations applicable to a materiel item, with. an indication of the lowest maintenance level that can perform the operations, a statement of the tools and test equipment required to perform the maintenance, and notes pertaining to its performance (Tables **4-1** through **4-3).** Basic portions of the maintenance allocation chart are established in the conceptual phase by the maintenance concept. The portions are refined and augmented as the materiel acquisition program progresses. The final document is based on either maintenance engineering analysis data or data from a separate document called the preliminary maintenance allocation chart. Preparation of the preliminary maintenance allocation chart is not initiated until the development phase.

Due to the interdependence of maintenance resource requirements, decisions reflected in the maintenance allocation chart cannot be made until many other equally important decisions are made. Data for these other decisions, as well as for the final maintenance allocation chart decisions, are contained in the maintenance engineering analysis data system or the preliminary maintenance allocation chart. The broad range of source data required to make the final maintenance allocation chart decisions is, therefore, much more important to the support planning process than the relatively limited data that are contained in the maintenance allocation chart.

The data in preliminary maintenance allocation charts differ slightly from maintenance engineering analysis system data. However, the difference is not evident in a broad discussion of the contents and purpose of the two data sources. Therefore, the discussion that follows is generic in nature and may be considered to reflect typical activities involved in developing either preliminary maintenance allocation chart or maintenance engineering analysis data to support maintenance allocation chart decisions.

Before development of source data is initiated, a maintenance concept is established as a result of trade-offs and analysis. The maintenance concept specifies the maintenance to be performed at each maintenance level. Functional and task analyses then are performed. The functional analysis expands the maintenance concept, and includes determination of functions such as repair, replace, inspect, etc., to a quite detailed level. The task analysis is a detailed analysis that identifies all required maintenance tasks and actions.

The task analysis, assuming that maintenance engineering successfully has influenced design, is probably the most important remaining maintenance engineering function to be accomplished. It is definitely the most important insofar as support planning is concerned. This analysis provides baseline data for determination **of**

a. Maintenance procedures to return materiel to or sustain it in operating condition. These procedures are the basis for technical publications and train-ing requirements.

b. Times required to perform corrective and preventive maintenance

c. Tools, test equipment, consumables, and repair parts required for maintenance

d. Operating and maintenance safety precautions

e. Required human factors studies

f. Troubleshooting routines.

Completion of the task analysis can result in modification of the maintenance concept or in a requirement for design changes. On the assumption of no changes, the maintenance task data are augmented with recoverability, essentiality, stockage, and failure rate data. The combined data provide the basis for identification and establishment of provisioning requirements.

In summary, either the preliminary maintenance allocation chart or maintenance engineering analysis data provide a great portion of the data required to plan the support of deployed materiel. The maintenance allocation chart data are more limited and therefore not as useful for planning.

4-6.3 PREVENTIVE AND CORRECTIVE MAINTENANCE

Both preventive and corrective maintenance requirements are assigned by maintenance level while the maintenance allocation chart is being developed. These requirements include both the maintenance actions to be performed and the resources that are used to perform the maintenance. The most significant difference in planning support for these two types of maintenance derives from the fact that preventive maintenance is accomplished on a prescribed schedule, whereas corrective maintenance is performed as the result of random failures.

In planning preventive maintenance, economical utilization of support resources usually can be realized, because the resources can be used on a production line basis. For example, it might be possible to calibrate 50 end items once a month with one set of calibration equipment, because the calibrations can be scheduled. This assumes that operational requirements can be satisfied with one item out for calibration and a certain number, based on reliability and maintainability predictions, out for corrective maintenance.

Planning for corrective maintenance is not as precise as planning for preventive maintenance. Since corrective maintenance is technically an unscheduled action based on failures that are random in nature, only an average workload can be calculated, manually without excessive expenditure of time. To circumvent this problem, dynamic simulation of materiel operation and maintenance over a period of time may be used. This tool permits the random application of failures and provides resulting downtime due to such factors as waiting for resources, preventive maintenance, corrective maintenance, and conflicting priorities. As a result, the planner is provided with data pertaining to peak workloads and resource utilization. Based on this information, corrective maintenance requirements can be planned more accurately and with less risk than is possible by manual application of average failure rates.

REFERENCES

1. MIL-STD-1388-1, *Logistic Support Analysis,* 15 October 1973.
2. NAVORD OD 39223, *Maintainability Engineering Handbook,* 1 February 1970.
3. TM 38-710, *Integrated Logistic Support Implementation Guide for DoD Systems and Equipment,* March 1972.
4. MIL-STD-721B, *Definitions of Effectiveness Terms for Reliability, Maintainability, Human Factors and Safety,* 25 August 1966.
5. AR 750-1, *Army Materiel Maintenance Concepts and Policies,* May 1972.
6. MIL-STD-781B, *Reliability Tests, Exponential Distribution,* 15 November 1967.

CHAPTER 5
MAINTENANCE ENGINEERING ANALYSIS

This chapter describes and discusses preliminary maintenance allocation charts, a typical maintenance engineering analysis data system, and maintenance factors.

5-1 INTRODUCTION (Ref. 1)

Maintenance engineering analysis is the dynamic catalyst in an integrated support program. During the early stages of a materiel acquisition cycle, the data identified by maintenance engineering analysis are general and parametric in nature. As the design progresses, and a product baseline is identified, support requirements are defined in increasing detail. Interactions between maintenance engineering and design engineering activities must be many, varied, and continuing, particularly in the early phases of a materiel acquisition program. Logistic feasibility studies are made concurrently and are correlated closely with technical feasibility studies. A continual dialogue is maintained between the design engineer and maintenance engineering as an inherent part of system development. This relationship maximizes possibilities for early identification of problems, thus forcing design versus support trade-off decisions before the design is finalized. Maintenance engineering analysis efforts during the conceptual, validation, and early development phases are of special importance, having the potential for major impacts on design, system supportability, and life cycle cost.

Maintenance engineering analysis provides for specific consideration of operator as well as maintenance requirements, and injects system support criteria into the design process at an early point in the acquisition cycle. Program essentials are analysis and definition of qualitative and quantitative support requirements, prediction of support costs in funds and other resources, and evaluations and trade-offs.

The foregoing discussion pertains to maintenance engineering analysis activities during materiel programs that involve design and development effort prior to production. Such programs provide maintenance engineering with the opportunity first to place major emphasis upon influencing design for supportability and then to place major emphasis upon designing the optimum support subsystem for the final materiel design. When the Army procures off-the-shelf equipment, or slightly modified off-the-shelf equipment, maintenance engineering has little or no opportunity to influence design. However, this does not negate the value of the maintenance engineering analysis process in optimizing a support subsystem for the equipment. All portions of the maintenance engineering analysis process which are useful in identifying support resource requirements apply equally to newly developed and off-the-shelf equipment. The only significant difference in the two applications is that the analysis process is iterative with regard to newly developed materiel and is virtually a one-time activity with regard to off-the-shelf equipment. Maintenance engineering analysis activities are documented by means of logistic support analysis data sheets that are described in MIL-STD-1388.

5-1.1 MAINTENANCE ENGINEERING ANALYSIS PROCESS

A systematic, comprehensive maintenance engineering analysis program that includes consideration of the projected materiel operational environment is conducted on an iterative basis throughout the acquisition cycle. This maintenance engineering analysis is the single analytical logistic effort within the system engineering process, and is responsive to acquisition program schedules and milestones. Maintenance engineering analysis is a composite of systematic actions taken to identify, define, analyze, quantify, and process logistic support requirements. The analysis evolves as the development program progresses. The numbers and types of iterative analyses vary according to the program schedule and complexity. As maintenance engineering analysis evolves, records are maintained that provide the basis for logistic constraints, identification of design deficiencies, and identification and development of essential support resources.

Initially, maintenance engineering analysis develops qualitative and quantitative logistic support objectives. **As** the program progresses, these objectives are refined into design parameters for use in design/cost/operational availability/capability trade-offs, risk analyses, and development of support capabilities. The initial effort evaluates the effects of alternative hardware designs on support costs and operational readiness. Known scarcities, constraints, or logistic risks are identified, and methods for overcoming or minimizing these problems are developed.

During design, analysis is oriented toward assisting the designer in incorporating logistic requirements into hardware design. The goal is to create optimum materiel that meets the specification and is most cost-effective over its planned life cycle. Logistic deficiencies, identified as the design evolves, become considerations in trade-off studies and analyses.

Periodically, the design and the hardware are subjected to formal appraisals to verify supportability features, such as accessibility and compatibility of test equipment, as specified in the contract. As the program progresses, and designs become fixed, the maintenance engineering analysis process concentrates on providing timely, valid data for all areas of support; e.g., maintenance, provisioning, personnel and training, and technical publications.

Detailed logistic support requirements are identified as the design of the end item becomes firmly established. The range and depth of analyses vary, depending upon the extent of materiel design definition and the goal of the analysis. Some analyses are highly iterative, while others are a one-time effort. Feedback and corrective action loops include controls to assure that deficiencies are corrected and documented. Generally, detailed analysis of support requirements is concentrated on line replaceable units (LRU's), modules and major assemblies/subassemblies, plus necessary tools, test and ground support equipment, etc.

5-1.2 MAINTENANCE ENGINEERING ANALYSIS TASKS

The flow diagram in Fig. 5-1 illustrates the overall maintenance engineering analysis process. The activities portrayed are highly iterative. Maintenance engineering analysis begins in the conceptual phase and continues throughout the materiel life cycle. Analysis tasks are shown on sheet 1 of Fig. 5-1. Sheet 2 shows that the analysis output data are manipulated either automatically or manually to identify support resource requirements. The manipulation of the data and the resulting outputs are discussed in par. 5-3. The maintenance engineering analysis tasks are:

a. Historical Data Review. A review of historical data is accomplished to relate past experience to the logistic support requirements of the new acquisition. Historical data will be used in development and verification of reliability and maintainability estimates, including frequency and time for maintenance factors. This review will use supply, maintenance, and operational information from operational systems, and other service or contractor information such as technical reports, combat records, and field exercises, as appropriate. One purpose of this review is to reveal trends in support concepts and indicate success/failure of these concepts on past or inventory systems/equipments. Additionally, the review will consider:

(1) High rate failure potential of subsystem, components, items, etc.

(2) Major downtime contributors

(3) Specific design features that will enhance logistic support

(4) Potential logistic support problem areas

(5) Design concepts with potential safety impact

(6) Design characteristic versus support cost

(7) Gross requirements for logistic support resources, such as manpower, equipment, and facilities.

These historical data establish a baseline value with respect to logistic support requirements for new acquisitions and provide indications for special attention if significant departures from this baseline are noted. Likewise, such data may furnish insight to justify new approaches or significant departure from traditional concepts. Thus, historical data may provide a basis for planning changes such as reducing or increasing the allocation of

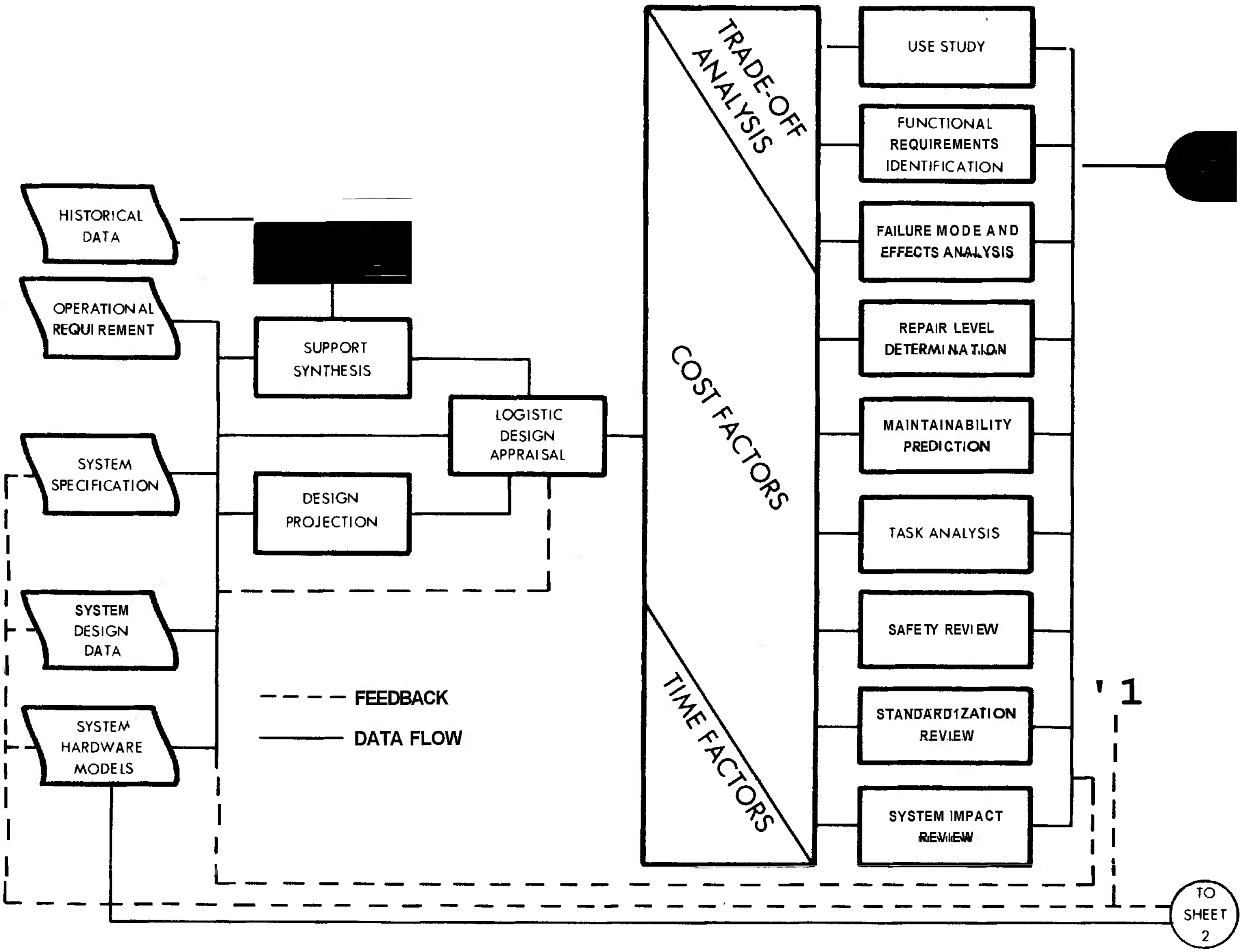


Figure 5-1. Maintenance Engineering Analysis Process (Sheet 1 of 2)

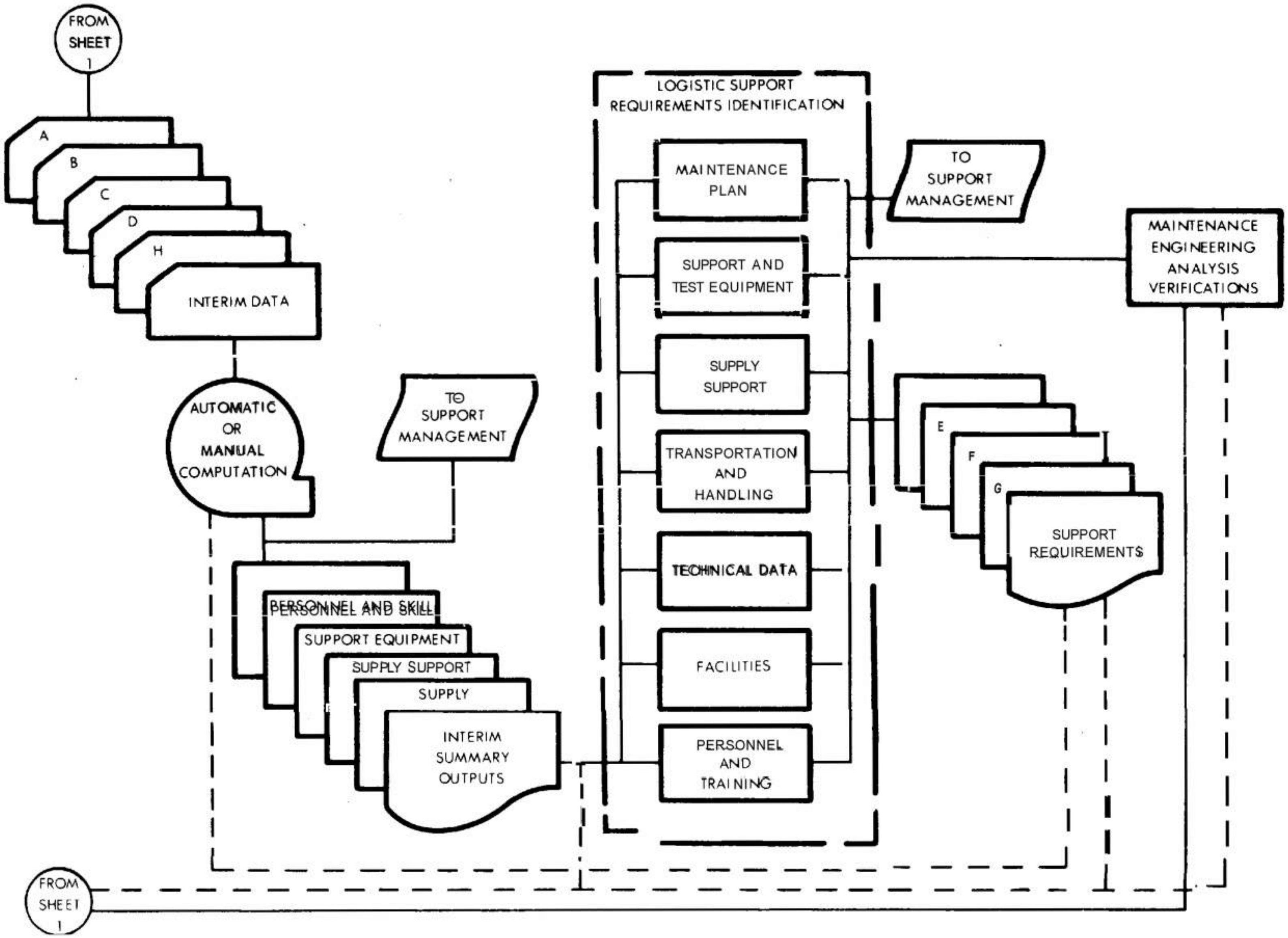


Figure 5-1. Maintenance Engineering Analysis Process (Sheet 2 of 2)

resources for maintenance, establishing different support procedures, reallocating maintenance workload among the different levels/categories of maintenance, or establishing different test and checkout procedures.

b. Support Synthesis. Support synthesis provides an organized basis on which to conduct support modeling evaluation of the proposed support subsystem and the framework for other analysis tasks. Synthesis is defined as the putting together of parts or elements so as to form a whole, or the assembly of various support approaches into conceptual support subsystems. Initiative and creativity are applied to influence equipment design for maintainability and logistic support. The analyst considers a wide variety of maintenance and support parameters within the restraints imposed by operational requirements and cost-effectiveness. Since a functional model or procedure with quantification is useful on all except the most minor acquisitions, synthesis data elements should be selected appropriate to the modeling technique used and the outputs required for the specific materiel procurement. Three basic areas shall be considered in performing the synthesis:

(1) Variables representing the system/equipment must meet the purpose of the investigation.

(2) The scope of the representation must be adequate.

(3) Care must be taken in the manner of describing the synthesized support system. Characteristics of each approach will be defined and quantified.

c. Design Projections. Design projections are used as detailed design progresses to detailed definition of hardware. These projections are used to develop estimated cost factors, functional requirements identifications, maintainability predictions, and other essential maintenance engineering analysis inputs, necessary for early synthesis/evaluation of the logistic support system.

d. Logistic Design Appraisal. A logistic design appraisal is an integrated part of program and design reviews held for the materiel. As a minimum, logistic design appraisals are conducted upon completion of conceptual design, prior to the release of design drawings for full-scale development, and upon completion of full-scale development. Informal support subsystem design appraisals are conducted at lower system indenture levels throughout full-scale development. The primary objective of the appraisal is to evaluate the projected design and, finally, the actual design upon completion of the full-scale development phase. Materiel design is reviewed for incorporation of support requirements from early in the conceptual phase through full-scale development. Specifically, the design appraisal considers the following:

(1) Logistic support for the total system

(2) Physical configuration, including structural arrangement, installation, controls, displays, mounting, accessibility of subcomponents, and transportability

(3) Maintainability considerations, such as standard versus special test equipment, online versus offline test equipment, component interchangeability, modularization, accessibility, criticality, standardization, and human factors engineering

(4) Component reliability or malfunction rate/mode of subassemblies.

Subsequent to the support system design appraisal, a systematic followup is performed to insure incorporation of changes defined for logistic considerations.

e. Trade-off Analysis. Trade-offs between support alternatives and equipment design parameters are made to provide an economical support subsystem that best satisfies the system operational requirements. The rationale and results of all trade-offs made are provided as specified by the procuring activity. Trade-off analysis normally involves the following considerations:

(1) The initial effort is directed toward identifying and listing these alternatives without consideration of the system model. Alternatives that are unacceptable are retained on a checklist but are omitted from in-depth consideration.

(2) Following refinement of the list of factors bearing upon the trade-off analysis, the analyst formulates a model or manual procedure that simulates the interrelationship of these factors. This model or procedure is examined against the total list of factors for possible pertinent omissions. It is emphasized that

the validity of trade-off decisions is directly dependent upon the completeness and thoroughness of the study.

(3) The analytical model or procedure is then tested and the various factors weighted as to importance and sensitivity. Care is used to keep the relationships in proper perspective relative to their importance.

(4) The analytical process follows model (or procedure) testing and validation. The various alternatives and related parameters are examined throughout the full, reasonable range. The results, including the rationale for selection and rejection of alternatives, are recorded and documented. Final disposition of such documentation is as directed by the procuring activity. The primary objective of the documentation is to define parameter relationships for subsequent iterations and model refinement.

(5) The nature of trade-off models depends upon both the acquisition phase and the system complexity. Trade-offs early in the program would be interdisciplinary and broad in scope. Restraints are based upon the cost, delivery schedule, and gross estimates of operational capability and system concepts. As development progresses, the inputs become increasingly more specific in substance, with the outputs influencing a more limited number of related parameters. However, it is essential that any proposed change be tested for its impact on the total system.

f. Cost Factors. Cost factors are prepared for use in the analytical trade-off process to provide the life cycle cost of development, procurement, operation, and support of proposed/selected alternatives. These should be based upon sufficient and adequate data, if available, from actual surveillance of operational systems to maximize confidence. These factors may be measured in terms of manpower, equipment, facility space, and supplies, as well as in dollars.

g. Time Factors. Time factors are identified and determined for equipment operation, transportation, maintenance, and supply as an intrinsic part of all tasks of maintenance engineering analysis. These time factors are used to determine system downtime as a measure of system availability/effectiveness, maintenance man-hour requirements, maintenance time standards, and supply response requirements. Time factor determination is essential for quantitative maintainability prediction that involves the statistical combination of time-to-accomplish estimates. Time factor determinations begin in the conceptual stage on the gross maintenance functions and continue through full-scale development when hardware design has progressed to the point that specific features are known. Time factors normally are determined earlier and in more detail for those functions or functional sequences in which time is critical to mission success, safety, use of resources, minimization of downtime, and/or increasing availability. Examples of data outputs are task time in man-hours; task time elapsed; time line of critical tasks; maintenance man-hour figures per operating hour; maintenance man-hour figures per year; maintenance man-hour figure per maintenance action; mean time between maintenance actions; mean time between overhauls; mean time to repair; and other time data associated with operation, transportation, supply, and the maintenance cycle.

h. Use Study. Studies on the use of the proposed materiel consider such factors as mobility, mission frequency and duration, operational environment, basing concepts, and anticipated service life as they relate to the operational requirements. Resulting data include annual operating requirements, consisting of number and duration of missions and number of operating days, number of systems supported, transportation time sequences, support profiles, allowable maintenance periods, and environmental requirements.

i. Functional Requirements Identification. This task identifies the support functional requirements as the frame of reference for developing support approaches. This task must be accomplished in time to provide a basis for concurrent consideration of support requirements with critical design decisions. Functional requirement identification progresses from gross functional levels, possibly with no mention of hardware in the conceptual stage, to a more formalized identification during full-scale development when the design has developed to the point that engineering drawings and hardware are defined in detail. Data associated with functional studies are addressed in the development program.

j. Failure Mode and Effects Analysis (FMEA). This analysis is performed, unless otherwise specified in the contract, to identify predicted materiel failures and effects of the failure. The analysis provides timely identification of deficiencies in the total system. Deficiencies are corrected through design changes or by proper logistic support adjustments to the extent mandated by functional mission requirements and safety considerations. To the extent possible, inherent catastrophic or critical failure effects are alleviated. Failure mode and effect analysis is performed at the beginning, in the early stages of system definition and design. The analyst first uses system functional level breakdown and flow block diagrams, as developed by the design, reliability, and maintenance engineering activities. As design progresses, the failure mode and effect analysis extends down to the lowest functional level. Examples of analysis output data are item failure modes, failure rates, failure symptoms, failure criticality, failure effects (primary and secondary), and detection methods, all of which are used as input data for maintenance engineering analysis.

k. Repair Level Determination. A repair level study is conducted to arrive at the optimum level of component discard and level of repair. The replacement unit size and the maintenance level are determined to define the various replace/repair action alternatives. Emphasis is placed on cost, operational availability, and operational effectiveness. Trade-offs among these three factors and any overriding restraints, such as deployment requirements and supply line reliability, form the basis for replacement unit and capacity decisions. The support resource requirements generated by the various alternatives—including personnel and training, technical data, support equipment, facilities, and replacement/inventory parts—are evaluated to determine the optimum level decisions. Mathematical models for computer simulation of the synthesized support subsystems should be used if the size of the system under development indicates that such an approach is cost-effective.

l. Maintainability Prediction. A maintainability prediction is conducted unless otherwise specified in the contract. The maintainability prediction is quantitative during the full-scale development phase. Prior to that time, quantification may be limited by uncertainty of design and scarcity of data; however, best estimates must be used in conjunction with other analysis activities that determine repair levels, establish logistic resources, and optimize support characteristics. Output data from maintainability prediction are system maintainability values associated with hardware indenture levels. These values include maintainability allocations, mean time to repair, mean downtime, mean time between maintenance actions, and man-hours per operational increment. The data are used as inputs to the analytical determination of logistic support requirements.

m. Task Analysis. This effort is a detailed investigation of the maintenance/operational functions to identify all tasks or actions required to accomplish them and will become the baseline data for the following:

(1) The organization of specific maintenance procedures that must be conducted to sustain or to return the equipment to operating condition. These procedures form the basis of the equipment maintenance manuals.

(2) Task time as vital for predicting maintenance time parameters

(3) Skill requirements and quantities of personnel necessary to perform the maintenance and operational tasks

(4) Tools, support equipment, expendable items, and spares/repair parts required to perform maintenance and operational tasks

(5) Minimizing the hazards associated with operating and maintaining the item

(6) Human factors engineering studies

(7) Facility and space needs for performing tasks.

As in many of the other areas of maintenance engineering analysis, task analysis is evolutionary. Maintenance times and personnel requirements are estimated in the conceptual stage and iterated on a continuing basis as the design progresses through full-scale development. The failure mode and effect analysis is the primary source for corrective maintenance task identification. Particular attention is given to fault isolation, servicing, and corrective and preventive maintenance. Data resulting from the task analysis result in a complete description of the maintenance function and include such elements as task description, task number, sequential actions comprising a task, task frequency, man-hours per task, task elapsed time, personnel requirements per task, replacement parts per task, and support and test equipment per task. The task analysis must depict clearly the relationship of tasks and functions in performing complete jobs. For example, the access and preparation tasks/actions for each fault isolation must be associated with the fault isolation task as well as with all possible corrective actions that could result. Task analysis is performed in greater detail as the design is defined. When an initial design has been established (at the end of validation phase), tasks are defined to the line replaceable unit level for use in determining manning requirements and level of repair. When detailed design data are available, tasks are broken down into step-by-step procedures and are used as the basis for technical data preparation.

n. Safety Analysis. An analysis is performed to optimize the safety characteristics of the materiel within the constraints imposed by operational requirements. The analysis identifies hazards and specifies measures to minimize the danger to personnel, as well as the unique support requirements identified thereby. The failure mode and effect analysis is used for identification of safety hazards. The responsibility for the system safety analysis should be independent of the system design function and should have recourse directly to top management.

o. Standardization Review. Unless otherwise specified in the contract, standardization reviews are conducted to achieve the maximum use of existing components, tools, support equipment, test, measurement, and diagnostic equipment and personnel skills without significantly inhibiting design improvement. New items introduced require justification that the items already in the system do not meet the approved military characteristics or safety requirements, the state of the art and technological advances require the introduction of a new item, or the new item materially will increase the overall effectiveness and modernization of the equipment under development. Design improvement trade-offs with the advantages of standardization may be cited as a reason for use of a nonstandard item. The key factor required in reducing the life cycle costs and enhancing effectiveness of logistic support is to standardize for both physical and functional interchangeability. Standardization in this regard also requires:

(1) Identicality of the end articles produced under contract, including identicality of internal parts, during the span of multiyear procurements and across lead and follow-on contracts, when applicable

(2) Intra-end article (intra-weapon system/intra-aircraft/intra-ship) standardization to insure the use of the minimum different components/equipments/items within the end article whenever the closest tolerance or highest output could become the standard (i.e., vertical standardization within a system) when horizontal standardization (i.e., between systems) is not practical

(3) Intra-departmental standardization (the design reuse of reliable components/equipments already supported in the specific department(s))

(4) Use of military standard parts in new design.

p. System Impact Review. Review is conducted to determine the impact of the proposed support system on other facets of the materiel. Additional features needed to enhance overall Operational capability and cost-effectiveness are identified. Constraints imposed by existing or proposed logistic systems (inventory, provisioning, support equipment, test equipment, personnel and training, and safety systems) also are identified and entered into system documentation. The support subsystem for the equipment under development is not designed as a separate entity; parallel design evolves in the development of the hardware and support subsystem. Early system impact review accomplishes the first mating of the system performance requirements with the requirements of the Army's overall logistic system. The concepts, policies, and principles established by operations and logistic support studies form the constraints of the support subsystem design and must be compatible with the mission and effectiveness requirement of the materiel. These concepts, policies, and principles dictate the allowable logistic resources and are the basis for statements of early requirements such as the specific maintenance levels to be used, preventive maintenance limitations, allowable personnel rates and numbers, and allowable maintenance downtime. Computerized modeling of the maintenance and supply system, if practical (depending upon acquisition requirements), is an important method of evaluating alternate approaches. Models are particularly valuable during trade-off studies involving maintainability/availability and life cycle costs that are conducted during early development effort. Depot workload and scheduling, provisioning and inventory factors, personnel factors, and the transportation process specifically should be examined.

5-1.3 MAINTENANCE DATA SOURCES

The preliminary maintenance allocation chart is a basic source of maintenance data resulting from maintenance engineering analysis. This document is comprised of four charts which basically assign materiel maintenance level responsibilities, identify required tools and test equipment, and provide appropriate remarks pertaining to maintenance actions. Although the document fails to bring together in one package all of the maintenance analysis data required for support planning, it provides a baseline for the derivation of other required data. Preliminary maintenance allocation charts are generated (normally by a contractor) during the development phase, evaluated during prototype demonstration (usually by materiel physical teardown), and, after approval, become a source of data for validating and refining the maintenance allocation chart.

Maintenance engineering analysis data systems, normally automated, provide another source of maintenance data. Preliminary maintenance allocation charts and maintenance allocation charts may be retrieved manually *or* by computer from these data systems. Use of a data system as a data source for the charts will insure that the allocation of maintenance tasks to maintenance levels is compatible with planned technical manuals, skills and manpower, tools and equipment, and other support resources.

5-2 PRELIMINARY MAINTENANCE ALLOCATION CHART (PMAC) (Refs. 2, 3, 4)

The preliminary maintenance allocation chart (PMAC) provides a basis for analysis of the design of materiel to identify maintenance requirements and design change requirements. Some commodity commands prepare the PMAC manually as described in the discussion that follows. Other commands extract PMAC data from automated maintenance engineering analysis data systems (par. 5-3.2*d*). The PMAC contains maintenance data directly or indirectly related to all support elements, and is used to develop the maintenance allocation charts (MAC) for the organizational technical manual. The PMAC is developed to be the basic maintenance decision document, and is used as the basis for provisioning, establishing maintenance procedures, planning for training, and determining tool and test equipment requirements.

Each development contract negotiated by a commodity command for materiel acquisition normally contains a requirement for the preparation and updating, within specific time limitations, of the PMAC's. Production contracts or companion engineering services contracts contain a requirement to maintain the PMAC's current with approved engineering orders.

The forms designed for the preparation of the PMAC's may vary slightly among commodity commands in order to meet the particular needs of a command. To further insure that the commodity needs are met, PMAC's are generated per contract specification when specific contract line items delineate Army Regulations, Data Item Descriptions and specific instructions and procedures to be followed. Any changes or variations may be directed by the command to the contractor by contract letter. Contractor changes to PMAC specifications may be made if approved by the command.

One of the major differences among existing PMAC's is the method of breaking down the major end item. The two primary methods used are listing by generation breakdown and by functional grouping. Certain commodities—such as vehicles, tanks, power stations, and generators—lend themselves to the functional grouping method. This method assigns group numbers to each functional portion of the overall end product and then proceeds to list the components that make up the group. For example, a vehicle would have its major functional groups listed as follows: 01 Engine, 03 Fuel System, 05 Cooling System, etc., and listed beneath the major groups would be its individual components that make up the group such as:

01 ENGINE

 0100 Engine Assembly:
  Engine
  Mounting, Engine
  Power Plant

 0101 Crankcase, Block, Cylinder Head:
  Head, Cylinder
  Cylinder, Sleeve and Piston Assy

 0102 Crankshaft
  Bearing, Crankshaft

Equipment such as specialized control and checkout equipment and test equipment, lends itself more to the generation breakdown method. This method lists the end item (a final combination of end products and/or component parts capable of performing a function without interdependency upon another item) and proceeds in top-down generation drawing sequence to tear down the item by listing all parts to the lowest level of disassembly. For example, a multimeter, as an end item, would be broken down in the reverse sequence of buildup; i.e., removal of knobs, case, assemblies, components, etc., down to the bare chassis. The listing would begin with the major assembly as the first generation level, the subassembly as the second, and the piece parts as the third.

Another difference that exists among PMAC's is the format of cover sheets. All cover sheets contain materiel identification information, revision data, approval authority, etc., but the information is presented in different sequences.

5-2.1 PREPARATION OF PMAC's

The PMAC contains a list of all items, down to the lowest level of disassembly, the recommended category of maintenance, recoverability aspects, essentiality, tools required to perform specific maintenance operations, and remarks required to explain the maintenance operation.

With the maintenance concepts established, additional knowledge required by the maintenance engineer—in order to develop a valid PMAC—is experience with the actual handling and repair of hardware, familiarity with standard shop practices and repair operations, and identification and utilization of common tools and test equipment. The maintenance engineer also must understand the following areas in regard to the materiel being analyzed:

a. Military characteristics for the item being evaluated

b. Maintenance plan for the system

c. Maintenance philosophy for the item being evaluated

d. Planned tactical deployment of the systems

e. Planned training of the personnel

f. Documentation package (drawings and specifications) for the item being evaluated.

Primary factors to be considered throughout the preparation of PMAC's are:

a. Maintainability of each item

b. Availability of tools, test equipment, and shop facilities

c. Distribution of repair parts and materials

d. Distribution of personnel skills.

Preparation of the initial PMAC's starts during the development program with the initial release of design documentation. Army and contractor maintenance engineering personnel should be throughly familiar with the established PMAC forms, the equipment documentation, and the development hardware. As the program develops, the contractor updates the initial PMAC's to the production configuration and plans for a formal PMAC review and maintenance evaluation to be performed, using the production prototype hardware and released production documentation.

For the initial preparation of a PMAC, a complete set of development documentation is required, along with accessibility. to the development hardware, the assembly line, and the design and manufacturing personnel. Hardware 'inspections and discussions are of particular value in those cases where the documentation does not define the requirements; i.e., tools and test equipment, procedures, skill requirements, etc.

Development of the PMAC during the development phase makes the analyst aware of unacceptable logistic deficiencies in the documentation and/or materiel and permits timely corrective action. Recognition of the deficiencies after the production program is initiated could result in costly redesign or the delivery of two materiel configurations and a subsequent modification program.

Standardization is another area in which much may be gained at this time. Maintenance engineering may identify proposed items that can be replaced by items currently in the supply inventory. Even if substitutions of the standard items result in design changes to interfacing items, the change may be amenable to justification on a life cycle cost basis; i.e., reduced procurement costs, support costs, supply management costs, etc. An example of this would be to standardize screw heads (all slot or all cross recessed) to reduce required quantities and types of tools.

5-2.1.1 PMAC Development Procedure

The major steps in a typical PMAC development cycle follow. Details could differ between commodity command-contractor teams, but the principles would remain unchanged.

a. The Army issues contractual requirements for the development of PMAC's.

b. Maintenance engineering performs an initial maintenance analysis effort and develops a draft PMAC, less certain data items to be identified later.

c. Maintainability and other technical support activities review an in-process copy of the draft PMAC, placing emphasis on major assemblies and associated maintenance operations, tools and test equipment, and remarks. Comments and recommendations are provided to maintenance engineering.

d. Maintenance engineering computes and assigns maintenance factors, assigns essentiality codes, and, in consultation with supply personnel, assigns recoverability and stockage codes.

e. Maintenance engineering distributes the completed draft PMAC to all contractor support elements, receives comments, and prepares a final draft PMAC.

f. The PMAC is sent to the Army for review.

g. Maintenance engineering incorporates Army comments and prepares and distributes the PMAC to the Army and to appropriate contractor organizations, including all of the support elements.

5-2.1.2 PMAC Description

The PMAC consists of a group of four charts (cover sheet, MAC page, tool page, and remarks page). Figs. 5-2 through 5-5 show the forms that comprise a typical PMAC with typical entries (save for the cover sheet, which shows no approval action). The following paragraphs describe all of the forms and the meanings of the codes on the MAC page:

a. Cower Page. The cover page (Fig. 5-2) identifies the chart number, date, page number, nomenclature, revision number, end item part number, end item nomenclature, next higher assemblies, approval agencies and signatures, the revision letter of the pages of the PMAC affected by the current and previous revisions, and the page numbers of all pages that have been revised, including the current revision.

b. MAC Page. The MAC page (Fig. *5-3)* provides a list of all maintenance significant items in a prescribed disassembly sequence. These items are listed by hardware generation breakdown, indenture, nomenclature, quantity, and part number. Columns A through R identify the overall maintenance functions of the equipment.

Columns A through K identify the detailed maintenance tasks to be performed. In relation to the items of equipment, appropriate codes for the maintenance levels that are to perform the specific tasks are entered in these columns. Normally, the codes used in the PMAC are numerical to represent the level of maintenance

Form D-1034
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PRELIMINARY
MAINTENANCE ALLOCATION CHART
COVER SHEET

:HART NO.	DATE	REVISION	PAGE	PAGES
11060079-9	15 April 1974		1 OF 29	

IOYENCLATURE
CABLE ASSEMBLY SET. ELECTRICAL

END ITEM NO.	NOMENCLATURE OF END ITEM
11060079	CABLE ASSEMBLY SET. ELECTRICAL

NEXT HIGHER ASSEMBLY

CONCURRENCE :

SIGNATURE:

REVISION

PAGE

REVISION

PAGE

REVISION

PAGE

Figure 5-2. PMAC—Cover Page

Form Oct 69 D-1034-A

PRELIMINARY
MAINTENANCE ALLOCATION CHART
MAC PAGE

CHART NO. 11060079-9 | DATE 15 April 1974
REVISION | PAGE 4 OF 29 PAGES

LINE NO.	INDENTURE (1-7)	NOMENCLATURE	QTY	PART NUMBER	A Inspect	B Test	C Service	D Adjust	E Align	F Calibrate	G Install	H Replace	I Repair	J Overhaul	K Rebuild	L Recoverable	M Essentiality	N Tools Req'd	O Remarks	P Demilitarization	Q Failure Rate	R M.O.S.
1.	3	INSULATION TUBING	1	MIS17329/1-3								3				Z		14		A	.001	46N20
2.	3	CABLE, ELECTRICAL	1	MPD10987, 010482, CL 1												Z			C	A	.001	
3.#	2	CABLE, ASSEMBLY, 60W109	1	11039209-39	2	2						2	2			D	M	1	AD	B	.074	21G20
4.	3	SHIELD, ELECTRICAL CONNECTOR	2	10608296-11								2				Z		8		A	.001	21G20
5.#	3	CONNECTOR, PLUG, ELECTRICAL	1	MIS17433/1-11								5	2			D		13	N	A	.036	21G20
6.	4	SLEEVE, ELECTRICAL CONNECTOR	1	MIS17419/2-3									2			F				A	.001	21G20
7.	5	RING, INDEX	1	ZZM9216-60E								2				Z		3		A	.001	21G20
8.	5	RING, SNAP	1	ZZM9016-39E								2				Z		3		A	.001	21G20
9.	3	BANDMARKER, CABLE	1	11039216-853								2				Z		4	F	B	.001	21G20
10.	3	ADAPTER, CABLE TO CONNECTOR	2	MIS17432/1-3								5				Z		13	O	A	.001	
11.	3	CABLE, ELECTRICAL	AR	MPD10987, S040752X, CL 1												Z			C	A	.001	
12.	3	BANDMARKER, CABLE	1	11039216-855								2				Z		4	F	B	.001	21G20
13.#	3	CONNECTOR, PLUG, ELECTRICAL	1	MIS17433/1-33								5	2			D		13	N	A	.036	21G20
14.#	4	SLEEVE, ELECTRICAL CONNECTOR	1	MIS17419/2-3									2			F				A	.001	21G20
15.	5	RING, INDEX	1	ZZM9216-60E								2				Z		3		A	.001	21G20
16.	5	RING, SNAP	1	ZZM9016-39E								2				Z		3		A	.001	21G20
17.	3	INSULATION TUBING	AR	MIL-I-23053/5, CL 1,L 50I, D.								2				Z		14		A	.001	21G20
18.	3	SPRING, RFI KIT	1	P205502-16		5						5						32	AC	A	.001	
19.	3	RFI EXPANDABLE BAND	2	TP201376-16								3				Z		15	P	A	.001	46N20
20.#	2	CABLE ASSEMBLY, 60W115	1	11038590-9	2	2						2	2			F	M	1	Q	B	.106	21G20
21.	3	CONNECTOR	1	10605215-77								3				Z		11	D	A	.053	46N20
22.	3	CONNECTOR	1	10605215-51								3				Z		5	E	A	.053	46N20
23.	3	CABLE, ELECTRICAL	AR	MPD10987, S040450X, CL 1												Z			C	A	.001	
24.	3	ADAPTER, CABLE	1	MIS17340/3-13								3				Z		5	D	A	.001	46N20
25.	3	BANDMARKER, CABLE	1	11039216-327								2				Z		4	F	B	.001	21G20

Figure 5-3. PMAC–MAC Page

(e.g., 1 = operator, 2 = organizational, 3 = direct support, 4 = general support, and 5 = depot).

Recoverable (column L) indicates whether or not the item is recoverable and returned to the supply system. The codes in this column may be but are not limited to the following:

F – Economically repairable at direct or general support maintenance level

D – Economically repairable at depot maintenance level

A – Items that contain precious metals, critical materials, and/or economically reclaimable castings, etc.

Z – Uneconomical to repair.

Essentiality (column M) indicates the mission essentiality of the item.

Tools required (column N) indicates the Arabic numeral code for the group of tools identified on the tool page required to perform the maintenance functions on the line item.

Remarks (column O) indicates the alphabetical letter code for the remarks, identified on the remarks page, listing the procedure and instructions required to perform maintenance functions on the line item.

Demilitarization (column P) indicates the alphabetical code (letters A through G) for the demilitarization of the line item. Specifically, code letter A indicates a nonmilitary item and demilitarization not required, Code letter B indicates a military item and demilitarization not required. Demilitarization of the line item, if required, is achieved by mutilation, burning, shredding, pulping, transfer of materiel, or other procedures furnished by the line item manager.

Failure rate (column Q) indicates the estimated failure rate per 100 items per year. A difference in failure rate and the maintenance factor would be covered in the remarks.

MOS (column R) indicates the minimum skill required to effect the test (column B) and repair (column I).

Other forms are in use that differ in varying degrees from the example shown. Items may be added or deleted depending upon the commodity command requirements.

c. *Tool Page.* The tool page (Fig. 5-4) lists all common and special tools, test, measurement, and diagnostic equipment, and calibration requirements needed to maintain the end item. Common tools and equipment are identified by set designation and stock number.

d. *Remarks Page.* The remarks page {Fig. 5-5) records specific instructions on the use of standard tools, special tools, test equipment, cleaning procedures, calibration requirements, precautionary measures, and other pertinent information that should be brought to the attention of maintenance personnel. All trade-off analyses containing the technical rationale for determination of maintenance operations and tool and test equipment requirements, as set forth in the MAC page, also are identified on the remarks page.

The cover page, tool page, and remarks page are straightforward and based on the decisions made during analysis of the end item when determining the maintenance functions for the items on the MAC page. A determination based on personal knowledge of the capabilities of the various categories of maintenance is required to assign a maintenance function to an item. In determining the maintenance level of repair, the following must be considered: level and extent of maintenance function, time required to perform maintenance, level and quantity of maintenance skills, common hand tools versus speed or automatic tools, test equipment, etc. For example, if the skill levels of direct support and general support personnel are similar, then the limiting factor in assigning maintenance becomes the time required and the cost involved to accomplish the repair. Selection of a maintenance level can be made by studying the failure rate and density of an item versus the cost of the required tools and test equipment to effect the repair. If the item has a low failure rate and density and the cost of tools and test equipment is high, then the repair of the item should be assigned to the general support or to the depot level. This assumes that operational availability will not be impacted adversely by the increased supply pipeline time that results from moving maintenance to a higher level.

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MARTIN MARIETTA ORLANDO DIVISION

PRELIMINARY
MAINTENANCE ALLOCATION CHART
TOOL PAGE

TOOL CODE	CAT.	NOMENCLATURE	TOOLNUMBER
1-b	2	TESTER, ELECTRICAL CABLE, AN/GSM-45C	6625-996-7294
	3	CABLE SHIELD RESISTANCE TEST SET 11039161	
	2	MULTIMETER, AN/URM-105C	6625-999-6282
	3	IGNITER CIRCUIT TESTER (ALINCO) P/N 10055154	
	3	SEALING COMPOUND, MPD 11883, TYPE II	8030-731-3578
1-h	2	WATER DISPLACING COMPOUND, 16 OZ AEROSOL CAN	6850-988-7068
2-h	3	PNEUMATIC AIR SCRIBE	5130-933-5250
	3	ADHESIVE, EPOXY RESIN, MPD 11881, TYPE IV	8040-059-5477
	3	WRENCH, PIPE STRAP STYLE, 1 TO 5 IN.	5120-262-8491
	3	PLIERS, SLIP JOINT, CONDUIT W/INSERTS	5120-624-8065
	3	PLIERS, DIAGONAL CUTTINC	5110-240-6209
	3	BIT, SCREWDRTVER, SLOT TYPE 320-5	5120-021-2002
	3	SCREWDRIVER, TORQUE, 2 TO 35 IN. -LB	5120-021-2041
	3	SCREWDRIVER, FLAT TIP, 3/16 IN. TIP, 6 IN. LG. BLADE	5120-278-1270
	3	SOLDERING IRON, ELECTRIC	3439-294-9011
	3	SOLDER, WIRE, ROSIN CORE	3429-273-2536
	3	PLIERS, RETAINING RING TYPE II	5120-293-0044
	3	COMPRESSOR, SNAP RING	5120-910-7502
	3	VISE, BENCH MOUNTED	4935-064-6809
	3	NOZZLE, CART, CALK, COMPOUND	5120-801-0949
	3	CARTRIDGE	5120-022-9801
	3	PLUNGER, CALK, GUN	5120-056-4828
	3	CAP, CARTRIDGE, CALK, COMPOUND	8125-996-9365
	3	POTTING GUN	5120-075-3335
	3	INSULATION COMPOUND, ELEC, EMBEDDING, MPD 11879	5970-926-0246
	3	FRAME, HACKSAW, ADJUSTABLE	5110-289-9657
	3	BLADE, HACKSAW, 10 INCH,	5110-142-4928
	3	ANTISEIZE COMPOUND TT-A-580, 1 PT.	8030-201-0996
	3	HANDLE, TORQUE WRENCH, 600-1600 IN. -LB	5120-020-5646
	3	WRENCH, OPEN END HEAD, 1-15/16 IN.	5120-020-5649
	3	HANDLE, TORQUE WRENCH, 150-750 IN. -LB	5120-020-5645
	3	WRENCH, OPEN END HEAD, 2 1/4 IN.	5120-020-5654
3-h	2	COMPRESSOR, SNAP RING	5120-910-7503
	2	PLIERS, RETAINING RING, TYPE II	5120-293-0044
4-h	2	FABRIC, COTTON, WHITE	7920-205-3571

Figure 5-4. PMAC– Tool Page

Oct69 D-1034-C

MARTIN MARIETTA ORLANDO DIVISION

PRELIMINARY
MAINTENANCE ALLOCATION CHART
REMARKS PAGE

CHART NO.	DATE	REVISION	PAGE	PAGES
11060079-9	15 April 1974		26	OF 29

CODE	REMARKS
A-a	INSPECT FOR DAMAGE (VISUAL) BEFORE OPERATION.
A-b	ELECTRICAL CABLES WILL BE TESTED FOR CONTINUITY, SHORTS, CONDUCTOR RESISTANCE AND INSULATION,
	USING CABLE TESTER AT 6 MONTHS INTERVALS. 'REFER TO TM 9-1430-380-14. USE TEST ADAPTERS IN CON-
	JUHCTION WITH CABLE TESTER. THE RFI INTEGRITY TESTS SHOULD BE CONDUCTED AT THE DSU USING CABLE
	SHIELD RESISTANCE TEST SET 11039161 LOCATED IN THE ELECTRICAL SHOP SETS. THE RFI INTEGRITY SHOULD
	BE VERIFIED EVERY SIX MONTHS.
A-h	CABLE ADAPTERS SHALL BE TIGHTENED UNTIL FULLY SHOULDERED OK THE CONNECTOR BARREL. TORQUE
	SHALL NOT EXCEED 85 FT. LBS. APPLY WATER DISPLACING COMPOC'ND TO THREADS OF EXTERIOR CONNECTORS.
A-i	REPAIR OF CABLE ASSEMBLY AT ORGANIZATIONAL LEVEL IS LIMTED TO REPLACEMENT OF CONNECTOR DUST
	CAPS, INDEX SLEEVES, AND CABLE BAND MARKERS.
B-b	USE TEST ADAPTER P/N 10512434-6 and -34 IN CONJUNCTIOK WITH CABLE TESTER.
B-h	APPLY WATER DISPLACING COMPOC'ND TO THREADS OF EXTERIOR CONNECTORS.
C	NO MAINTENANCE FUNCTION WILL BE PERFORMED. IF DARIAGE OCCURS REPLACE NEXT ASSEMBLY.
D-h	REFER TO REMARK E-h. WHEN CONNECTOR IS REPLACE, ENGRAVE THE SAME SERIAL NUMBER ON THE NEW CON
	NECTOR IN THE SAME POSITION AND SAME CHARACTER SIZE AS ON OLD CONNECTOR. APPLY A THIN COAT OF
	ADHESIVE MPD 11881. TYPE IV OVER THE ENGRAVED AREA.
E-h	APPLY LUBRICANT MIL-L-60326 TO INNER SURFACE OF CONNECTOR COUPLING NUT TO PREVENT EXCESS ADHES-
	IVE FROM GETTING UNDER THE NUT. CLEAN LUBRICANT FROM COKKECTOR THREADS AND CLEAN ADAPTER
	THREADS WITH SOLVENT MIL-C-18718, AND APPLY ADHESIVE MPD 11881, TYPE IV SPARINGLY TO INTERNAL
	THREADS OF ADAPTER BEFORE RMTING WITH CONKECTOR. ADAPTERS TO BE POTTED PER SPECIFICATION MPD
	11879 - OUTER JACKET OF CABLE SHALL BE INSERTED INTO POTTING COMPOUND NOT MORE THAN HALF THE
	LENGTH OF THE ADAPTER, OR LESS THAN .50 INCH. MATE CABLE PLUGS INTO A MATING RECEPTACLE PRIOR
	TO POTTING TO INSURE PROPER ALIGNMENT. CABLE ADAPTER SHALL BE TIGHTENED UNTIL FULLY SHOULDERED
	ON THE CONNECTOR BARRELL. TORQUE SHALL NOT EXCEED 85 FT-LB.
F-h	CLEAN AREA FOR BANDMARKER WITH SOLVENT MIL-S-18718 AND ALLOW TO DRY. APPLY BAND MARKER AT
	ROOM TEMPERATURE OF 65°- 90° F. SEAL WITH BRUSH COAT OF EPOXY RESIN OVER BANDMARKER - OVERLAP
	EDGES.
G-h	TORQUE CABLE CLAMP SCREWS TO 18 ± 2 IN.-LB.
H-h	EACH CRIMPING TOOL HAS TWO OR MORE DISTINCT DIES WHICH ARE USED TO CRIMP DIFFERENT SIZED FERRULES.
	EACH DIE IS COLOR CODED SO THAT THE PROPER DIE CAN BE READILY DETERMINED BY MATCHING THE COLOR
	OF THE FERRULE WITH THE SAME COLOR ASSOCIATED WITH A PARTICULAR DIE. FOR EXAMPLE, A GREEN
	COLORED FERRULE REQUIRES THE HEX DIE WITH A GREEN DOT.
I-b	USE TEST ADAPTERS, P/N 10512434-37 & -62 IN CONJUNCTION WITH CABLE TESTER.
I-h	APPLY WATER DISPLACING COMPOUND TO THREADS OF EXTERIOR CONNECTORS.
J-h	CABLE CLAMP SCREWS TO BE TORQUED TO 7 ± 1 IN.-LB.

Figure 5-5. PMAC—Remarks Page

5-2.1.3 Maintenance Level Assignment

Determination of the maintenance level to be assigned to a maintenance function is based upon the capabilities of established Army maintenance levels. These levels are identified as organizational, direct support, general support, and depot. A description of their typical capabilities follows.

a. Organizational maintenance is the maintenance authorized for and performed by, and which is the responsibility of, the using organization on its own equipment. Organizational maintenance consists normally of inspection, cleaning, servicing, preserving, lubrication, adjusting as required, and minor part replacement not requiring highly technical skills.

Organizational maintenance is divided into operator maintenance and technician maintenance.

(1) Operator maintenance is that degree of maintenance performed by the operator in providing proper care, use, operation, cleaning, preservation, lubrication, limited adjustments, and replacement of common hardware parts, without extensive disassembly of assemblies, components, or end items.

(2) Technician maintenance is that maintenance accomplished by specially trained technicians within the using organization, and includes the performance of

(a) Periodic inspection and scheduled services

(b) Replacement of all items authorized for usage

(c) Adjustment and repairs on assemblies, components, and end items that can be accomplished without extensive disassembly and with tools authorized to the organization.

b. Direct support maintenance is that degree of maintenance performed by specially trained units in direct support of using organizations. Direct support maintenance includes:

(1) Replacement of items authorized for usage

(2) Repair of electrical, mechanical, and hydraulic assemblies, subassemblies, and end items

(3) Repair of electronic assemblies by subassembly replacement

(4) Repair of the overflow from lower levels within limits imposed by authorized tools, time, repair parts, and test equipment

(5) Fabrication of parts from bulk material.

c. General support maintenance is that maintenance performed by semimobile or fixed shops in support of direct support maintenance. A general support unit is primarily engaged in the repair of major items, assemblies, and subassemblies for return to supply channels. General support maintenance includes:

(1) Replacement of all items authorized for usage

(2) Repair of end items

(3) Repair of electrical, mechanical, and hydraulic assemblies and components

(4) Repair of electronic assemblies and subassemblies, with the exception of missile electronics

(5) Fabrication of general-use common hardware and parts

(6) Repair of the overflow from lower levels within the limits imposed by authorized tools, time, repair parts, and test equipment.

d. Depot maintenance is that maintenance performed by fixed shops engaged in:

(1) Complete overhaul or rebuild of major items

(2) Reconditioning of assemblies, subassemblies, and end items for return to supply channels

(3) Replacement of all parts authorized for usage, and fabrication of parts not otherwise economically obtainable.

5-2.1.4 Formal Review

The PMAC normally is approved through formal review procedures. The review team is comprised of Army personnel responsible for materiel supply, maintenance, technical publications, provisioning, and other support activities. Contractor personnel may be invited to attend the review as technical consultants. The review normally is accomplished during the latter part of the development phase. Subsequent to approval, the PMAC is updated as a part of the engineering change program.

Resources required for the review are the involved materiel, all materiel documentation, the PMAC, and the tools listed on the PMAC tool page. Additionally, a conference room and shop area are required. The review is accomplished by comparing the PMAC with the documentation and hardware on a line item-by-line item and entry basis. The teardown sequence, quantity, part number, maintenance level assignment, tool requirements, etc., are confirmed or modified.

The PMAC cover page is revised and a new concurrence obtained for any revision to a PMAC page that changes the maintenance concept used in the evaluation. Other revisions are noted on the affected PMAC pages.

5-2.1.5 PMAC Revision

The PMAC must be maintained throughout the life cycle of materiel to reflect the current design and the support subsystem. When a change is made to the documentation and/or equipment which affects the PMAC, the change to the PMAC must be incorporated within a specified number of days after the documentation and/or equipment change is approved by the Army. This is accomplished by integrating the maintenance engineering analysis effort with the contractor's engineering change program.

Revisions to the PMAC receive the same treatment and level of analysis as those associated with the development of the original PMAC. The same procedures apply to the generation and processing of revisions to PMAC's as those used in the generation and processing of the original PMAC's.

Whenever an engineering change is proposed, maintenance engineering reviews the engineering change package to determine the change for impact on the PMAC documentation. The cost of any PMAC impact is included in the total change package when submitted to the Army for approval. Upon approval, the engineering change is incorporated on a scheduled basis into materiel hardware and software. A new PMAC reflecting the changes is prepared and distributed to all recipients of the previous edition.

5-2.2 AUTHORIZED VARIATIONS OF PMAC's

Different organizations may require different maintenance data. As previously stated, contracts may be written and PMAC forms may be designed to include whatever data the procuring agency requires.

The following subparagraphs describe some data elements that might appear in whole or in part in some PMAC's and not in others:

*a. **Mean Active Corrective Maintenance Time.*** This information is useful in scheduling workloads at various maintenance levels, and to insure that repairs assigned to the organizational level do not adversely affect operational availability. Such times may be established by conducting maintenance task analyses or by applying formulas. A typical formula consolidates optimistic, most likely, and pessimistic maintenance time estimates, and produces a probable time.

*b. **Source Code.*** This code indicates the source for acquiring an item for replacement purposes. For example, the code might indicate that an item is procured and stocked, manufactured, fabricated at a specified maintenance level, or assembled.

*c. **Recoverability Code.*** This code indicates the disposition of an unserviceable item.

*d. **Overhaul Factor.*** This factor represents the quantity of repair parts required to overhaul 100 items.

*e. **Military Occupational Speciality.*** This element identifies the qualitative skill required to perform a maintenance task.

f. Unit Pack. This quantity identifies the number of unit packages of a repair part that is shipped in an outer package or container.

The transfer of PMAC data to a MAC sometimes generates a problem. Normally, the PMAC is prepared in disassembly sequence for teardown of maintenance significant equipment. Transition of the PMAC into the MAC results in some of the hardware items being assigned functional group codes.

Those maintenance significant items not assigned functional group codes are listed alphabetically at the beginning of the functional group listing prior to the listing of the coded items within the group. An example is the following:

0320 Azimuth Ring Assembly
- Azimuth Ring
- Clamp Section Assembly
- Crank, Hand
- Gear Assembly, Speed Decreaser
- Gear, Sector, Spur
- Ring, Launch
- Tube Assembly, Metal
- **0325** Dampener Base
- **0330** Cable Assembly
- **0340** Release Mechanism, Pneumatic
  - Bracket, Electrical Switch
  - Clamp Section Assembly
  - Cylinder
  - Frame, Mounting

As depicted, the functional group **0320** Azimuth Ring Assembly consists of nonfunctional group coded items (Azimuth Ring through Tube Assembly, Metal) listed alphabetically and the functionally coded items **(0325, 0330, 0340)** within the overall functional coded group **0320. As** illustrated, both the alphabetical items and the coded items are in the second indenture. In the **0340** function code at the third indenture, the items are again alphabetically listed. The basic problem resulting from this type of coding and/or arrangement is the difficulty the user has in locating specific items on the chart and the loss of the hardware disassembly sequence that is available on the PMAC.

The general solution to this dilemma would be to assign functional group codes to all hardware items in numerical sequence according to systematic hardware disassembly arrangement.

5-3 LOGISTIC SUPPORT ANALYSIS DATA SYSTEM (Refs. 1, 5, 7)

The logistic support analysis data system is a typical system for the management of maintenance engineering data to insure that all aspects of logistic support are recognized and considered during materiel planning, design, development, and deployment. The data within the system comprise the logistic support analysis record. The data system provides a method for collection, storage, manipulation, and retrieval of data for engineering and logistic analysis, and for insuring integration of the activities of the support elements. Proper use of this data system will insure that logistic support documents pertaining to parts, tools, equipment, personnel, training material, facilities, etc., are compatible with other documents that provide maintenance instructions, skills, level of repair determination, etc.

Compatibility is achieved by using the logistic support analysis record as a common data base for developing the many documents that define and allocate logistic support resources. The procuring activity may alter or supplement the record, as necessary, to meet requirements.

Data provided by the procuring activity, generated by coincident engineering requirements, and derived through maintenance engineering analysis are input to the logistic support analysis record through input data sheets. These data sheets, structured for a particular acquisition program, are filled in as data become available. Such data sheets also act as checklists to assure that the analysis provides adequate visibility of logistic support resource requirements at all levels of hardware indenture.

a. Data Item Description Requirements. The logistic support analysis record is used by maintenance engineering as the common data base for support development. The data generated during the course of the development program are used to satisfy the applicable data item description requirements of the various support elements associated with the program.

The objectives of using logistic support analysis data to satisfy data item description requirements are:

(1) To assure that parts, tools, and equipment authorization documents are compatible with other documents that provide maintenance instructions, skills, and authorized repair tasks. Compatibility can be achieved only by using a common data base for developing the many documents that allocate integrated logistic support resources and authorize parts and skills.

(2) To reduce data acquisition cost by:

(a) Reducing engineering analysis effort required to develop duplicate data

(b) Reducing the number of data systems maintained by the contractors

(c) Reducing delivery of duplicate data

(d) Reducing the generation of data to satisfy data item description requirements to an automated data processing extraction, requiring only cost of machine printout time.

b. Data Generation and Documentation. Data are generated by maintenance engineering analysis conducted on the items under development (or procurement, if an off-the-shelf item). This analysis establishes the maintenance actions to be performed upon the item and determines the support resource requirements necessary to accomplish the maintenance actions.

The data system stresses the flexibility of approach that maintenance engineering analysis must take in order to explore all aspects of design as they relate to the system operational and support environment. In the application of the maintenance engineering methodology, a variety of sequences may be used to arrive at the maintenance decisions required during a development program. For this reason, the sequence of entry of data upon the data sheets contained in the data systems often may be tailored to suit the engineering activity conducting the analysis. Interim, ancillary, and supplemental data required or desired during the course of the analysis may be entered into the data bank, integrated, and stored by using the data sheet control information.

c. Data Review. In general, the review will use summary sheet extracts from the data bank as indicators of the status of the analysis and documentation effort. The review assures that the data reflect currency of the analysis with latest revision of design drawings and that the data bank is capable of providing the output data products required at that stage of the development program. Review and acceptance of data normally are accomplished by an integrated logistic support team, which is formed to monitor logistic support planning for major systems, or by other personnel designated by the responsible maintenance point or support manager.

d. System Purpose. Use of logistic support analysis data is divided into two broad categories. One is concerned with evaluation of the maintenance aspects of design and the communication of facts and information for making decisions concerning maintainability, maintenance, and logistic support aspects. The other is to document and communicate decisions that have been made to those concerned with planning for and acquiring the resources to support the materiel.

Proper use of the logistic support analysis data is prerequisite to the achievement of integrated logistic support goals. These goals require that the total system support package be developed to implement the same maintenance plan. This fact is sometimes overlooked by sup' port element managers who demand that data for their areas be based upon redundant and separate analyses. The result is generally high acquisition costs for data and the identification of support resources that are incomplete, incompatible with each other, and not consistent with the materiel maintenance plan.

Maintenance engineering must assure that the logistic support analysis data generated throughout the development program merely are not accumulated and then ignored, but are used throughout the program as the primary source of all support development data. A policy must be established that forces all program activities to use the data as the common basis for support planning and development and as a cost-effective source for satisfying contractual data requirements.

e. System Content. The logistic support analysis record contains standardized data elements 'that provide detailed support requirements and serve as a tool for managerial decisions relative to allocation and funding of resources. The input/output formats, storage, and filing of these data complement the technical data systems of the program and assure integration of support element and design activities. Requirements for products pertaining to selective tasks, functions, reports, etc., are obtained from the stored data as required by the data item descriptions. The logistic support analysis record always reflects the current materiel design configuration.

f. Specific Input/Output Requirements. The range, depth, and specific input/output requirements for the data system are identified in the data system plan.

Inputs will be provided by cognizant functional elements (e.g., reliability, maintainability, producibility, availability, human factors, system engineering, design, or logistics). Data generated by maintenance engineering analysis should adhere to the standard data elements of the data system. The outputs from the data system should be in accordance with the contract data item descriptions.

(1) *Inputs.* In order to accomplish the maintenance engineering analysis effort, maintenance engineering requires design and logistic data inputs, including operational requirements, logistic system data, drawings, and hardware specifications. The following is typical of the initial information required:

(a) *Maintenance:*

1. Long-range service maintenance policies

2. Maintenance organizational structures

3. Maintenance equipment economic factors

4. Other maintenance planning inputs.

(b) *Support and Test Equipment:*

1. Existing equipment

2. Government/contractor-furnished equipment interface considerations

3. Existing calibration procedures and capabilities

4. Support and test equipment economic factors

5. Service policy and procedure for identification, selection, development, and acquisition of support equipment

6. Requirement dates.

(c) *Supply Support:*

1. Long-range supply concepts

2. Present and projected supply structures

3. Government-furnished materiel

4. Standardization policy

5. Usage and inventory data

6. Economic factors.

7. Other supply constraints or policies.

(d) *Transportation and Handling:*

1. Standard packaging procedures and materials

2. Containerization policies

3. Shock, vibration, hazardous material, and handling specifications

4. Transportation modes

5. Route and security restraints

6. Storage and shelf life requirements

7. Economic factors

8. Other transportation and handling factors.

(e) *Technical Data:*

1. Availability of technical publications for Government- or contractor-furnished equipment

2. Maintenance aids

3. Special features

4. Economic factors

5. Requirements for technical publications, drawings, etc.

6. Validation and verification requirements and schedules

7. Engineering and logistic data.

(*f*) *Facilities:*

1. Standard facilities criteria
2. Environmental consideration
3. Site data
4. Construction specifications
5. Utilization factor
6. Economic factors
7. Other service policies and procedures.

(*g*) *Personnel and Training:*

1. Existing skills available
2. Standard service manning structures
3. Existing training facilities/aids
4. Service training techniques
5. Economic factors
6. Long-range service personnel policies.

(2) *Outputs.* The data developed by maintenance engineering analysis are used as the analytical basis for determining logistic support resource requirements. Additional data are developed and provided to system design activities in the form of recommended design constraints for incorporation in system documentation, and as inputs to risk analysis, effectiveness studies, and system trade-off studies.

(*a*) Early information used for support planning includes such data as maintenance concepts, reliability, maintainability, maintenance task time analysis, compatibility, qualitative maintenance, applicable specifications, presentation format (e.g., maintenance dependency charts, maintenance aids, and computer/software and microfilm aids), special features or innovations, and technical data cost factors.

(*b*) Interim products may take the form of summaries of integrated support requirements. The summary extracts provide visibility to the important resource requirements and availability parameter achievements of the system design. Summaries are retrieved as needed whenever such visibility is required ?or program review, support planning, or further analysis. Analysis summaries generally are not considered to be deliverable data items in the contract. Their use is internal to the maintenance engineering function for review and analytical purposes, and their generation requires only the automatic data processing of existing analysis data. Typical applications of logistic support analysis data system summaries are:

1. For periodic assessment of support impacts as required to determine adherence to the design to support requirements of the contract.

2. To display logistic resource requirements for assignment to the work breakdown structure, and to determine further program funding, inputs to life cycle costing studies, etc.

3. For evaluation of analysis efforts by Government integrated logistic support teams. These summaries are reviewed by the teams as an indication of areas covered by the analysis effort and to assist in locating areas that require a more thorough review of detailed maintenance data.

4. For support planning. These summaries provide an excellent means of communicating logistic requirements to the support elements.

5. To consolidate selected data for further analysis. Many maintenance engineering decisions associated with the development of support requirements are made after initial analysis of the equipment design has been made. Logistic resources identified in the initial analysis worksheets, once summarized, facilitate follow-on decisions concerning equipment standardization, maintenance factor determination, stockage and allowance quantities, establishment of part kits, determination of support equipment utilization and allowances, etc.

(*c*) Final outputs of the data system are the logistic data specified in the contract data requirements list.

g. Identification of Maintenance Resources. Maintenance engineering analysis determines the maintenance resources required to support a proposed design configuration. The extent of identification depends upon the magnitude and complexity of the materiel and the phase of the acquisition cycle. As materiel development progresses and a basic design configuration is established, the identification becomes a process of analyzing specific design data to identify more completely detailed support subsystem requirements. This portion of the maintenance engineering analysis studies and completely defines the requirements for maintenance planning and support resources as described in the following subparagraphs:

(1) *Maintenance Planning.* For maintenance planning purposes, the maintenance requirements of the system are delineated in a manner such that they form the guideline for tracking support element activities. Initially, maintenance engineering analysis strives to establish the concepts and goals that the development program must achieve in regard to the maintenance characteristics of the system. Throughout conceptual and detailed design, the analysis documentation keeps pace with and reflects the current state of proposed maintenance for the system. This is done by describing, to increasingly lower indenture levels, the type of maintenance and support required by the system design. Data required from logistic support analysis for the maintenance plan include reliability and maintainability parameters and requirements, maintenance concepts, descriptions of maintenance organizations, correlation of maintenance tasks to maintenance units, task time, maintenance standards, maintenance repair limits, and facility requirements.

(2) *Supply Support.* Maintenance engineering analysis identifies all the system requirements for supply support. The delivery and positioning of materials for operational support are addressed, and the impact upon supply facilities, equipment, personnel, and procedures are evaluated for the system support approaches under consideration. Data resulting from the analyses for supply include the following: complete spares and repair part provisioning data containing identification, consumption, and usage rates, stockage and allowances, and source, maintenance, and recoverability coding.

(3) *Technical Data.* Maintenance engineering analysis provides the data necessary for the preparation of technical data. The analysis considers the ultimate technical manual requirements as soon as practical in the acquisition cycle to make timely plans for the formulation and validation of technical data. Delivery of technical data is paced by the actual design, and close liaison is maintained within the design activity to implement timely procurement. The scope of the technical data encompasses the total materiel program, and the impact on technical data of engineering change proposals and design changes is determined, with appropriate revisions made to maintain currency. Data resulting from analysis for technical data include complete identification of data required, technical manual size, page requirements, data presentation media, number and type of illustrations required, criteria for including subsystem elements into single documents, and criteria for combining several maintenance organizational data requirements into single documents.

(4) *Facilities.* Maintenance engineering analysis identifies all the facilities required to support materiel throughout system testing, training, operation, and maintenance. Preliminary information is developed during the conceptual phase and is further refined so that final facility planning may be accomplished by the end of the full-scale development phase. Changes and improvements in materiel design are reflected in the facility requirements. The facility items identified are cross-referenced with specific maintenance requirements. Realistic scheduling makes optimum use of facilities and at the same time permits performance of the maintenance functions in a timely manner. Data resulting from analysis associated with facilities include facility identification and description, capital investment requirements, facility design criteria, facility costs, leadtime, and any special considerations. Facility considerations include requirements for mobile, portable, and/or air transportable vans, mobile maintenance facilities and/or shop, and supply or storage containers as operational, maintenance, and support concepts dictate.

(5) *Support and Test Equipment.* Maintenance engineering analysis provides a comprehensive identification of the support and test equipment required at all levels of repair. During program initiation, usable

existing equipment is identified so that minimum peculiar equipment is developed. A major constraint on support and test equipment requirements is a standardization program that requires optimum use of existing equipment, modified existing equipment, and commercial equipment before the development of new equipment. This should take into consideration the possible modification of any existing equipment to suit the needs of a specialized requirement. The primary sources of input to determine the equipment needs are repair level studies from which the repair level, discard level, and maintenance concept are formulated. Data resulting from analysis associated with support and test equipment include complete equipment identification, maintenance level required, quantity of equipment required per unit/operating location, equipment function and capability, technical manual requirements, logistic requirements, measurement requirements, calibration requirements, equipment specifications, and special requirements.

(6) *Transportation and Handling.* Maintenance engineering analysis defines the transportation and handling requirements, including packaging and storage considerations, necessary for the support of the system/equipment. The procuring activity specifies the appropriate specification or standard to follow in establishing these requirements. The requirements are refined continually as the design evolves during full-scale development. This area of the analysis provides enough design feedback to insure that the basic materiel, support equipment, repair parts, etc., are designed to be compatible with available modes of transportation and handling equipment. Special transportation considerations, such as in-transit storage, security, guards, customs procedures, vehicles, and routing, are defined. Data resulting from analysis required for transportation and handling include transportation modes and times, container requirements and codes, packaging requirements, preservation requirements, and special transportation considerations.

(7) *Personnel and Training.* Maintenance engineering analysis defines the personnel, training, and training 'aids required for support of the materiel. Coordination is maintained with the cognizant design activities so that improvements and changes can be reflected in the personnel and training plan. Analysis provides identification of the necessary actions to provide trained operators and support and instructor personnel, and defines proficiency requirements in these skills at all organizational levels as defined by the procuring activity for all systems, installations, components, equipment, and related support items. Data resulting from analysis for personnel and training requirements include personnel quantities, skill levels, skill specialization, man-hours, training, training procedures, and training aids.

5-3.1 LOGISTIC SUPPORT ANALYSIS INPUT DATA SHEETS

The purpose of the logistic support analysis data system is to provide a standardized medium for systematically recording, processing, storing, and reporting data during maintenance engineering analysis. The data system is developed as the single source of validated, integrated, design related logistic data pertaining to an acquisition program.

Formal data are maintained only for those items determined to be subject to maintenance or operational actions, unless otherwise specified by the procuring activity. The detailed requirements for the logistic support analysis data are tailored by the procuring activity to suit the specific characteristics of the materiel. The magnitude, scope, and level of detail must be consistent with the stage of development; namely, parametric in the conceptual phase versus detailed in the development and production phases. The range and depth of the maintenance engineering analysis tasks for contractors are defined by the procuring activity.

The content and use of the input maintenance engineering data sheets are summarized in the paragraphs that follow. The logistic support analysis data system is adaptable to either manual operation or automated data processing techniques; for this reason, the structure of the data sheets takes into consideration the requirements for data processing. Inasmuch as the data content of the data system is defined by the content of the individual data sheets, the discussion that follows pertaining to data sheet content will be useful in gaining an exposure to the data available within the data system. The use of the data sheets is illustrated in Table 5-1.

TABLE 5-1. LOGISTIC SUPPORT ANALYSIS INPUT DATA SHEET UTILIZATION

DATA SHEETS	A	B	C	D	E	F	G	H
SYSTEM	X	X	X	X	•	•	•	X
SUBSYSTEM	•	X	X	X	•		•	X
LOWEST REPAIRABLE ASSEMBLY		X	X	X				X
PART								X

X = Data sheet normally required.
• = Data sheet dependent upon program requirements.

LEGEND:
A = OPERATIONS AND MAINTENANCE REQUIREMENTS
B = ITEM *R&M* CHARACTERISTICS
C = TASK ANALYSIS SUMMARY
D = MAINTENANCE TASK ANALYSES
E = SUPPORT AND TEST EQUIPMENT OR TRAINING MATERIAL DESCRIPTION AND JUSTIFICATION
F = FACILITY DESCRIPTION AND JUSTIFICATION
G = SKILL EVALUATION AND JUSTIFICATION
H = SUPPLY SUPPORT REQUIREMENTS

5-3.1.1 Synopsis of Data Sheets

The contents and format of the data sheets are such that:

a. The data sheets provide data and information for preparing publications and maintenance procedures, tool selection, task and skill analyses, maintenance allocation charts, special kit requirements, repair part selection, etc.

b. Data that can be machine processed are entered into machine records. Narrative-type data are microfilmed and filed in a repository, the location of which is identified in the machine records for ready retrieval purposes.

c. To provide for both manual and automated data processing applications, uniform control fields and standard header fields have been incorporated on the top section of each data sheet.

d. The data element definitions (DED) are grouped alphabetically and are referenced by a sequential number. The instructions for completing each data sheet are addressed by card and block instruction that has a standard header as follows:

Card Number ---------Block Number ---------Title ---------Related DED Number ---------Data Field Length ---------Type of Character.

EXAMPLE: Card A01; BLK 1: Functional Group Code; DED No. 041; 11X:

5-3.1.2 Operation and Maintenance Requirements (Data Sheet A)

Data sheet **A** is structured to display a consolidated picture of operation and maintenance requirements affecting the design engineer, logistician, maintenance man, and operational planner. The purpose of the end item maintenance requirement summary is to consolidate the pertinent data relating to the environment in which the system will be maintained, the anticipated operation of the system, and the allocation of maintenance requirements imposed on the system.

The data required for completion of data sheet **A** are generated prior to full-scale development. These data originate either from

Government planning activities, or from the performance of contractor feasibility studies. Normally, these data entries are made by the Government and supplied to the contractor. Data sheet A is prepared for the end item and the major subsystems to the functional level for which maintenance requirements have been established. This data sheet contains such data as:

a. Annual operating requirements: the estimated or required yearly usage amount

b. Annual number of missions: the specified or estimated number of missions performed annually

c. Annual operating days: the average number of days per year that a mission demand will be placed on an item

d. Mean mission duration: the average length of mission

e. Maintenance requirements: the data elements to specify the maintenance requirements by maintenance level as follows:

(1) Organizational level maintenance

(2) Intermediate/direct support maintenance

(3) Intermediate/general support maintenance

(4) Depot maintenance.

f. System/end item availability as follows:

(1) Mean time to repair: the sum of the corrective maintenance elapsed times divided by the total number of unscheduled maintenance actions during a given period of time

(2) Mean time between failures: the sum of the functioning life of a population of an item divided by the total number of failures within the population during the measured intervals

(3) Availability: the degree (expressed as a probability) to which an item is in the operable and committable state at the start of the mission, when the mission is called for at an unknown (random) point in time.

(4) Mean active maintenance downtime: the mean active downtime for a given interval

(5) Mean time between maintenance actions: the mean time between actions for a given interval.

5-3.1.3 Reliability and Maintainability Characteristics (Data Sheet B)

Data sheet B serves a key role in the maintenance engineering analysis process. It is one of the basic entry points for data produced by the coincident reliability and maintainability programs. The three basic types of data recorded are failure data associated with the hardware components of the system/equipment, including failure modes, frequency, and effects; maintainability review data pertinent to the design program; and the detailed maintenance concept for the item under analysis.

During the validation phase, a data sheet B is prepared for each item down to an indenture level that gives sufficient detail for the bidder to propose numerical maintainability requirements as contractual goals. The maintainability considerations contained on data sheet B are a guide for evaluating individual design features. The maintainability review data are developed as a result of maintainability requirement analyses that usually are conducted primarily by maintainability engineering. Usually, the specific quantitative requirements for maintainability are not easily determined from a cursory review of the system operational requirements. The requirements may be inextricably tied to or governed by other system effectiveness parameters and, as such, a number of iterative trade-offs are required to derive the requirements.

The maintainability requirements derived should be those that "optimally" balance the requirements with respect to other system effectiveness parameters, operational factors, and logistic requirements.

The development of failure data and failure mode and effect information is normally the responsibility of the design activity or reliability support group. However, if not provided, the failure mode and effect analysis may be performed by the maintenance engineer using procedures outlined in reliability and engineering handbooks. These procedures are used to identify and quantify the critical failure modes inherent in the design. These critical failure modes are defined as those resulting in an inoperative system, an unsafe operating or maintenance condition, or an aborted mission. A failure mode and effect analysis of the design studies the way in which all possible failures occur, and the attributable causes. The failure effect data are used to form the basis for development of the fault isolation flows used in the task analysis effort.

The task analysis effort is performed to identify maintenance support resources. The failure data recorded on sheet B provide a substantial start in determining the required maintenance task and frequency.

The failure mode effect analysis provides the analytical basis for design guidance in circumventing or minimizing the effects of critical failures.

The maintenance concept describes the maintenance approach envisioned for the item and establishes a baseline for life cycle costing. Usually, the operational requirement will have been defined for some preconceived system support environment. Whether the basic criteria are explicitly defined or only implied by the operational requirement, a system support plan and maintenance concept must be evolved to provide the practical basis for design, layout, and packaging of the system and its test equipment. The maintenance concept also establishes the scope of maintenance responsibility for each level of maintenance and identifies the personnel resources (maintenance manning and skill levels) required to maintain the system. Because of organizational separation of maintainability engineering and maintenance planning functions, the respective objectives of these two functions usually are pursued independently of each other and are made mutually compatible in the trade-off studies that follow. The recommended procedure, however, is to establish close liaision between the two functions at the outset to facilitate mutual interchange of maintainability analysis data and maintenance planning data during the maintenance concept formulation phase.

During the full-scale development phase, the B sheets provide for continued monitoring of design by day-to-day reviews. The design impact related to maintenance parameters is noted and the maintenance plan updated and definitized accordingly. In this phase, additional data sheets are completed for lower indenture levels of the system, to include each repairable item. Data sheet B should be microfilmed and filed in a data bank associated with the automated logistic support analysis data bank.

Data sheet B contains such data as:

a. Mean time between failures

b. Mean time to repair

c. Mean time between maintenance actions

d. Maintainability information to serve as a guide for individual design features and as a basis for initial quantitative maintainability predictions

e. Maintenance concept impact information that indicates whether or not special/peculiar support/test equipment, special/peculiar tools, or additional/special facilities are required for the performance of maintenance

f. Failure analysis information that includes failure modes, failure symptoms, failure effect and criticality, percentage of failure rate, repair time, task code

g. Item function information that describes the function of the item in sufficient depth to indicate clearly the function, specifications, and tolerance

h. Qualitative maintainability design requirements.such as fail-safe requirements, environmental requirements, etc.

i. A concise and clear statement of the maintenance and support concept for the item.. The planned or envisioned method that will be used to sustain the systems/equipment at a defined level of readiness or in a specified condition in support of the operational requirements

j. Remarks: amplifying remarks when any maintainability considerations are listed as "not adequate", or maintainability recommendations for consideration and justification of the current maintenance concept.

5-3.1.4 Task Analysis Summary (Data Sheet C)

Data sheet C identifies all maintenance and operator tasks and their related resource requirements; e.g., skill specialty codes, personnel requirements, task times, and support and test equipment. The coincident maintainability and human engineering programs provide data sources.

Data entered on data sheet C have two primary functions: to provide a sound basis for recommending changes to the configuration or design approach when supportability is marginal or unsatisfactory; and when the requirement for a particular maintenance or operator function is justified, to provide data for planning logistic support. Data are developed to the indenture level for which the reliability and maintainability characteristics have been identified (data sheet B). When alternate maintenance approaches are identified, a separate task analysis summary may be prepared for each approach. During full-scale development, data sheet C is completed for significant maintenance and operator tasks on each repairable item.

Data sheet C contains such data as:

a. Task code components:

(1) Task function: the applicable task function (e.g., inspect, test, repair, etc.)

(2) Task interval: the applicable task interval (e.g., scheduled, unscheduled, weekly, etc.)

(3) Maintenance level category code: the code for maintenance level (e.g., organizational, direct support, etc.).

(4) Operability code: the code of the operating condition of the item during the task function

(5) Task sequence code: the code for all similar tasks.

b. Task frequency: the annual occurrences based on the annual system operating requirements. It is used to compute the frequency of all tasks identified with the end item.

c. Elapsed time: the total elapsed time required to perform the task for allocated times, predicted times, and measured times:

(1) Allocated: the time allocated for the task which must be met in order to attain the overall maintenance requirement goals.

(2) Predicted: the predicted task time. During the detailed design and development stage, this prediction is substantiated by a task analysis (data sheet D). During early design, the time prediction may be based upon an overall evaluation of required task without carrying analysis to the detail required on data sheet D.

(3) Measured: the task time measured during performance of the actual task.

d. Pilot rework/overhaul candidate: the code that indicates whether or not the item is a candidate for an overhaul process analysis.

e. Skill level, skill specialty, and skill specialty evaluation: the skill level code required, skill specialty code of the service, and skill specialty evaluation of knowledge required to accomplish each maintenance action or other operational task.

f. Number of men per task and man-hours: the number of men required for a task and the hours allocated, predicted, and measured for each task.

g. Facility requirement code: the code that denotes whether or not a facility requirement exists. Data sheet F must be prepared to describe and justify requirements.

h. Training equipment requirements: the code that denotes whether or not training equipment is required to perform the task. Data sheet E must be prepared to describe and justify requirements.

i. Support equipment requirements: the code that denotes the need for and identifies the type of support equipment required. Data sheet E must be prepared to describe and justify requirements.

j. Tool requirement: the code that denotes the special tool or common tool requirement. If a special tool is indicated, data sheet E must be prepared to describe and justify the special tool.

5-3.1.5 Maintenance Task Analysis (Data Sheet D)

Data sheet D is completed for each task code assigned on data sheet C. Data sheet D describes how each maintenance and operator task is to be performed in terms of other related logistic support elements, and explains the tasks entered on data sheet C, provides descriptive information for development of technical manuals and other equipment publications, provides source information for personnel and training requirements, and identifies common tools, repair parts, and materiel necessary for the maintenance task.

Data sheet D contains such data as:

a. Task code: identified on data sheet C *b.* Task identification: a brief descriptive title of the function to be performed in the task (e.g., replace brake assembly)

c. Safety hazard code: the code that identifies any real or potential safety hazard that may exist during performance of the task

d. Sequence line number: the number that identifies the sequence of steps required (e.g., alignment or disassembly)

e. Work area: the work, area where the task is to be performed

f. All tools, material, and parts used during performance of the task

g. Total elapsed time and man-hours for the task.

5-3.1.6 Support and Test Equipment or Training Material Description and Justification (Data Sheet E)

Data sheet E describes and justifies the requirements for support or training equipment and special tools that are necessary to support the materiel. This information is necessary to provide the Government proponent for support equipment and tools the necessary information for evaluating proposals to introduce new items of equipment into the Government inventory. The data sheet also is used for evaluation of proposed items of training equipment. Special (peculiar) tools are assigned the data sheet control number of the materiel generating the requirement for the special tool. This information is listed on data sheet D under "Item Usage".

During the validation phase, data sheet E is prepared to the level of end item or system definition available and is revised and updated during full-scale development. Additional data sheets are prepared covering requirements determined subsequent to validation. Data sheet E is microfilmed and filed in a data bank associated with the automated maintenance engineering analysis data bank.

Data sheet E contains data such as:

a. Type item: specifies that the item is support equipment, a special tool, or training equipment, and that it is contractor furnished equipment or Government furnished equipment

b. Operating dimensions and weight: the length, width, height, and weight of the item in its operating condition

c. Storage dimensions and weight: the item considered in its packing or storage status

d. Procurement method: the recommended procurement method, the cost of development and other nonrecurring costs, the recurring costs, the total quantity recommended, and the extended unit price

e. Requirements: the task requirements that indicate the need for the support equipment, special tool, or training equipment

f. Description and function: the narrative description of the type of item and the functions it will be required to perform

g. Characteristics: the design and operational factors of the proposed item that affect maintainability and reliability, such as built-in test equipment, redundancy, backup system, mean time between failures, and mean time to repair

h. Additional skill requirements: the training or skills required to operate and maintain the proposed item

i. Installation factors: the vibration and shock mounting requirements, special foundations, utility connections, input, and limiting environmental factors that influence the installation of the item, and any equipment necessary to install the item (e.g., cranes, hoists, etc.).

5-3.1.7 Facility Description and Justification (Data Sheet F)

Data sheet F describes and justifies the requirements for all facilities necessary to support the system/equipment. This information is required for each task on data sheet C for which facilities are required. Data sheet F provides facility design personnel with the technical requirements that the system/equipment places on the support facility.

Facility requirements encompass all facility references from task descriptions on data sheet D. Location and quantity of facilities are identified by maintenance level.

Data sheet F contains data such as:

a. Task code: the task code that specifies **a** requirement for facility space

b. Facility requirements: a narrative description of the facility requirements that will encompass all the descriptive facility references from the task description on data sheet D. Specifies location and quantity of facilities required by maintenance level.

c. Facility design criteria: the requirements for items to be installed within the facility, turning space, clean-room, ventilation, etc.

d. Facility installation leadtimes: installation leadtime for the contractor to produce and install support equipment, or for training equipment installation and use. Reference leadtimes to system equipment delivery dates rather than to calendar dates.

e. Type of construction: construction type required if different from the type normally provided. Includes any special construction, such as shock, hardness, and special floor loads.

f. Utility requirements: the summary or estimate of the total connected load or gross quantity of utilities required. Utilities are classed as power, hydraulic, compressed air, water, or sewage.

g. Facility utilization: the facility utilization rate in terms of number of tasks performed in facility annually, training sessions, flying hours per month, number of maintenance hours per month, and other appropriate designators identified with the systems.

h. Facility unit cost: comment on reasonableness of the appropriate unit cost in terms of differences because of unusual utility requirements or other special features. If no suitable unit cost is available, a unit cost estimate is provided for each facility item.

i. Justification: the reasons and factors that contribute to the requirement for additional facilities other than those in current inventory.

j. Standard facility plan(s) or single-line sketches: a rough sketch of the facility requirements of the system, or a standard for the facility.

5-3.1.8 Skill Evaluation and Justification (Data Sheet G)

Data sheet *G* describes and justifies any new or unique personnel skills required to support the systemlequipment. These data are required for each task on data sheet C which identifies a skill that is not currently included in the military service's personnel skill structure, or a skill that requires modification. These data provide general information and justification for identifying and selecting MOS's from which personnel may be obtained for those duty positions requiring a new or revised MOS.

Data sheet G should be begun in sufficient time to provide source data for the draft qualitative and quantitative personnel requirement information. This sheet will then be updated to include all changes in the final qualitative and quantitative personnel requirement information.

Data sheet G contains data such as:

a. Duty position requiring a new or revised skill is identified and a new or proposed skill is indicated (e.g., sonar operator or demolition expert).

b. Skill speciality code: when a new code has been assigned, it is entered to indicate that the requirement has been fulfilled.

c. Armed Forces qualification test percentile score: the minimum score deemed necessary to qualify the candidate for required training

d. Security classification code: the minimum degree of security classification the candidate would require to undertake training

e. Recommended rank/rate/grade: the grade of civilian (Civil Service) recommended for specified training. The minimum military rank or rate required to undertake the training for the skill requirement.

f. Task code: the task code that generates the requirement for additional training

g. Additional skill requirements: a description of the additional requirements that necessitate the creation of a new skill specialty code

h. Physical and mental requirements: any special knowledges, skills, abilities, or physical and mental requirements necessary for the new or revised skill specialty code

i. Educational qualifications: any additional qualifications, such as academic subjects, specialized degrees, or licenses, required for the new or revised skill specialty code *j.* Justification: the reasons and factors that contribute to the requirements for additional skill and training for the system/equipment operation or maintenance

k. Additional training requirements: a narrative description of the training course(s) necessary and the estimated length of course, hours of instruction, recommended sites, and prerequisites for training instructors.

5-3.1.9 Supply Support Requirements (Data Sheet H)

Data sheet H identifies the items of supply support required to operate and maintain the system/equipment.

Data sheet H contains data such as:

a. Time between overhauls: the time period after which the item is to be overhauled, expressed in months

b. Maximum allowable operating time: time between calibration, inspect, repair, test, or condemn

c. Task function: the action to be performed for maximum allowable operating time after operating time period

d. Turnaround time (contractor): the estimated number of days required by the contractor to ready an item for reissue

e. Quantity per system/end items: the total quantity per assembly

f. Phased provisioning: determination of whether or not phased provisioning is required

g. Source, maintenance, and recoverability code

h. Production leadtime: the time in months between ordering of the item and receipt of the item

i. Type item code: the code best describing the item for which the data sheet is being completed

j. Shelf life code: the code that specifies when the item will be considered unusable due to age or deterioration

k. Usable on code: the code that identifies the assemblies, systems, or end items on which the item can be installed

l. Total quantity recommended: the total recommended quantity to be purchased to support all applications within the end item

m. Allowance qua'ntity for organizational/direct/general/depot level: allowance quantity as determined by computing method furnished by using activity

n. Failure factors: the replacement factors or quantities for various levels of maintenance, including information such as maintenance replacement rate or depot overhaul factor

o. Maintenance task distribution: the percentage of repairable quantities received by maintenance levels that can be performed at the individual levels.

5-3.2 Data Output Reports

The data in the logistic support analysis data system are stored and used in whatever form is necessary in order to plan the support required by the materiel. Report format and content for internal use by the contractor's maintenance engineering and support element activities are tailored to meet the particular requirements. Some of the output reports are sample outputs from maintenance engineering analysis, and the format and contents can be varied depending on the user's requirements. Other reports are interim in nature and may be used to check system performance.

Reports that are deliverable are prescribed on the contract data requirements list and supporting data item descriptions. The output reports may be generated manually for a minor acquisition or by automatic data processing for a more complicated procurement. The Army Materiel Command currently is planning the preparation of computer programs that will provide the summary reports that follow. AMCP 750-XX (Ref. 7) should be consulted, when formally published, to determine if report requirements have changed.

a. Direct Annual Maintenance Man-hours by Skill Specialty Code and Category of Maintenance. This report would be requested by the analyst interested in the annual man-hour requirements for each maintenance level, listed by skill specialty code. The data provide the skill specialty code and annual man-hours expended, and further break down the man-hours to the level of repair at which the annual man-hours are expended.

b. Personnel and Skill Summary. The analyst would request the skill specialty code for all operators and maintenance personnel by system. The data are presented by skill specialty code and the data sheet control number to the repairable assembly by sorting to the skill level code and identifying the repairable assembly by the data sheet control number. The task code identifies the maintenance level, function, and interval of the task and specifies the operating status of the materiel. The task frequency identifies how often the task will be performed to establish the annual man-hours. The skill specialty evaluation defines the requirement for additional training and the requirement for a'new skill specialty code. Each task is segregated to the maintenance level by man-hours and to total annual man-hours by work breakdown structure for each skill specialty code. The report can be used to determine the time required and the number of personnel by skill to perform each task.

c. Reliability and Maintainability Summary. The analyst would request the reliability, maintainability, and availability factors for the system or assembly, and the maintainability concepts and considerations.

The report is identified by the end item code to the program level. The data sheet control number is for the system or assembly level specified by the user, or it can be specified in a report for each assembly within the materiel. The reliability factors (mean time between failures and mean time between maintenance actions) are derived from the values specified for allocated, predicted, and/or measured reliability. The maintainability factors (mean time to repair and mean active maintenance downtime) are defined in the same manner as the reliability factors. The availability factors (availability inherent and availability achieved) are derived from the reliability and maintainability factors. The maximum allowable operating time is the period of time between calibration, replacement, etc., and the task function code defines the action to be taken after completion of the time specified'in the maximum allowable operating time. The time between overhauls is the time between overhauls or rework and is provided to identify how the unit can be protected from failure by overhauling or reworking before failure. A narrative ,section provides the overall description (under "Item Function") of the item and how the item will be maintained.

The report summarizes the failure information, repair time, availability, service life, function, and maintenance concept for each repairable item. The summary can be used to evaluate the function and reliability of each item within the materiel.

d. Preliminary Maintenance Allocation Chart. The analyst would request the lowest level of maintenance for each task to be performed on an assembly.

The columns of the report are the individual maintenance functions as defined in the first digit of the task code. The lowest maintenance level category code is entered against each of these functions by data sheet control number, and the man-hours expended on the task are listed under each function. The header for the report identifies the end item and the date on which the report was prepared.

The report summarizes the distribution of tasks by function and maintenance level, and shows the tasks assigned to each level of maintenance and the functions performed. The report is required for writing the maintenance manuals and provides data from which the maintenance allocation chart may be extracted.

e. Support Equipment Utilization Summary. The analyst would request a summary by individual type support equipment (or training equipment), requesting its utilization and the value of .the item being repaired (in the case of support equipment).

The header identifies the end item, the end item work breakdown structure, and the using service. The support equipment part number, name, price, and procurement method are identified to provide a comparison of different manufacturers of the same type of support equipment.

The use of the proposed or selected support equipment is outlined by the assigned maintenance level and the tasks it will be required to perform. The cost of the item being repaired by the support equipment is given so that the expense of the support equipment can be compared with the value of the item being repaired.

The report summarizes, by type of support equipment, the use of the equipment by maintenance level and work breakdown structure. The use of the equipment is referenced to the cost of the item being repaired. The report can be used to justify the requirements for support equipment and to determine the quantity and distribution requirements.

f. Tool and Equipment Requirements. The analyst would request a listing of all tools required to support a system or end item by the skill specialty code. A second requirement would be for a special tool list by system or end item. The report generates a listing of all tools, both common and special, needed to accomplish the maintenance and operation tasks. The report provides the tools by skill specialty code, part number, stock number, tool name, price, description, and function.

g. Repair Part Summary. The analyst would request the information necessary to perform the provisioning function for a system/end item/repairable item and part. The report provides the time between overhauls, task function, and shelf life of the part for determining the maintenance cycle. The part is identified by manufacturer's part number, item name, reference number, and manufacturer. The quantity and price of the item are given, and the replacement factors are given as failure factors. Failure factors can be substituted for the maintenance and overhaul factors. The report is designed to provide the information necessary to perform provisioning and to establish allowance list requirements.

h. Support Equipment Requirements by Category of Maintenance. The analyst would request the functional requirements of the support equipment or training equipment by data sheet control number.

The report provides by maintenance level the functions to be performed by the support equipment or training equipment. The task frequency and elapsed time provide the use of support equipment, and establish the quantity required. The data provide the capability requirement of the support equipment or training equipment and provide the information required to make a decision when competitive items of support equipment are being considered.

The report summarizes how and where the support equipment will be used at the various levels of maintenance. The report provides the requirements, quantity, and justification for the acquisition of support and training equipment.

i. Organizational Repair Part and Special Tool List. The analyst would request a list of the repair parts and tools required at the organizational level. The report provides a summary of repair parts and special tools for each major subsystem; i.e., air frame, communications, missile, etc. The report may be used as an interim repair part and special tool list prior to the operational phase.

j. Direct Support, General Support, and Depot Repair Part and Special Tool List, The analyst would request a list of the repair parts and tools required at all maintenance levels above the organizational level. The report provides a summary of repair parts and special tools required for each major subsystem at the direct and general support and depot maintenance levels.

k. Provisioning Requirements. The analyst would request all available provisioning information. The report provides the total range of data available for initial provisioning and related maintenance decisions. The data are used as an input to **ALPHA** for the generation of specific provisioning documentation.

5-4 MAINTENANCE ENGINEERING INFLUENCE ON SUPPORT

Maintenance engineering analysis exerts considerable influence on design decisions and, as a result, the ultimate cost of support. Greater awareness of total life cycle cost implications is vital to sound decision making on the design and support alternatives developed through maintenance engineering analysis. Acquisition cost alone is not a sufficient measure of effectiveness in view of the enormity of the support costs during a materiel life cycle.

Costs are the basic selection criterion for trade-offs relating to design and support. The costs associated with each equipment design alternative are computed, and the least costly alternative that provides the desired effectiveness'is selected.

The costs generated during a materiel life cycle are composed of three major cost categories: research and development, initial investment, and operating and maintenance. The cost factors contributing to the three categories are shown in Fig. 5-6(A).

Fig. 5-6(B) shows, in simplified form, the cost history of typical materiel. The costs for each of the three major cost categories are represented by the areas under the smoothed curves, typically displaying successive maximums. It is the magnitude of the operating and maintenance costs, determined and fixed by decisions early in the life cycle, which challenges the maintenance engineer.

Maintenance engineering analysis has a dual role in life cycle costing efforts. It influences design, thereby affecting research and development and investment costs, and it defines the support subsystem, which also affects investment costs and almost completely determines operating and maintenance costs.

Among the factors influenced by maintenance engineering analysis are:

a. Maintenance functions and tasks

b. Piece part, modular, or throwaway design

c. Other design features

d. Repair level

e. Replacement unit

f. Maintenance skills

g. Mean downtime

h. Number of personnel (direct and indirect)

i. Range and quantity of repair parts

j. Type and quantity of tools and test equipment

k. Type and volume of technical manuals

l. Type and amount of training

m. Type and amount of transportation

n. Type and size of facilities

o. Contract maintenance

p. Technical assistance

q. Technical data (other than formal technical manuals)

r. Initial and recurring supply management effort

s. Amount of research and development effort

t. Amount and type of testing

u. Amount and type (selection) of maintenance float

v. Other management/analysis effort.

These factors influence system design and support configurations and, as such, impact total system cost. During the maintenance engineering analysis process, these factors must be reviewed to insure the selection of a configuration (alternative) that is effective and economical to operate and maintain. The purpose of the maintenance engineering analysis is to optimize and provide a more accurate determination (quantitative and qualitative) of the logistic support requirements.

Throughout development, cost analysis provides for review, evaluation, and reduction of cost information and for determination of cost/performance relationships. These relationships and other cost factors applied with the information developed by maintenance engineering analysis permit the preparation of estimates that provide life cycle cost visibility to decision makers at all levels of the materiel development program. The maintenance engineer, in his role of decision maker, seeks to provide the required support effectiveness at the lowest cost burden. This cost-effectiveness optimization of the logistic support design is involved in every iterative application of maintenance engineering analysis. This includes due consideration of total cost implications in tradeoff analyses and in the selection of support resources.

In order that the effectiveness of cost analysis be maintained, it is important that timely and accurate data be used. Every effort should be made to acquire sufficient data from actual surveillance of systems in an operational environment. If, however, adequate data of this type are not available, it may be necessary to resort to various estimating techniques. Many of the factors affecting the cost of developing, procuring, operating, and maintaining an item

Research and Development Costs

(1) System Development
- (a) Preliminary study and design
- (b) Design engineering
- (c) Hardware fabrication

(2) System Test and Evaluation
- (a) Equipment fabrication
- (b) Test programs (including reliability and maintainability)
- (c) Test equipment
- (d) Facilities

(3) Other System and Development costs
- (a) Maintenance and supply support
- (b) Miscellaneous

Initial Investment Costs

(1) Equipment
- (a) Initial procurement
- (b) Repair parts
- (c) Initial transportation
- (d) Installation

Initial Investment Costs (Cont'd)

(2) Personnel
- (a) Increased manpower requirements
- (b) Initial training
- (c) Initial travel

(3) Facilities

(4) Miscellaneous Investment costs

Operating and Maintenance Costs

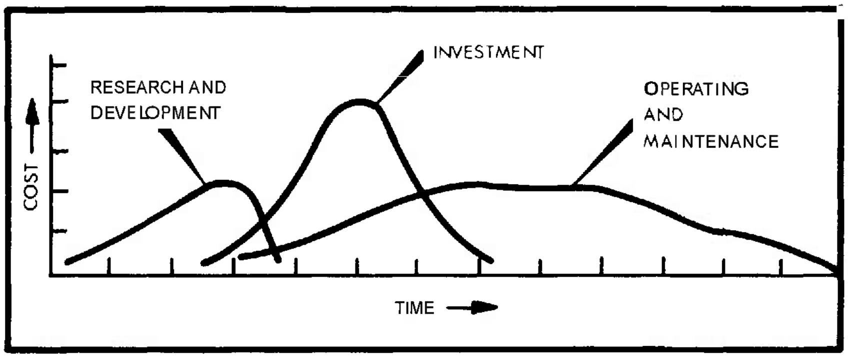
(1) Equipment
- (a) Operation
- (b) Training allowance
- (c) Annual transportation
- (d) Maintenance

(2) Personnel
- (a) Pay and allowance
- (b) Training
- (c) Travel

(3) Facilities

(4) Miscellaneous Operating costs

(A) MATERIEL COST CATEGORIES



(B) TYPICAL MATERIEL COST HISTORY

Figure 5-6. Life Cycle Materiel Costs

are dynamic. Therefore, timely collection of input data is required if the cost analysis is to depict current conditions in the system.

5-5 MAINTENANCE FACTORS (Ref. 6)

The maintenance factor of a repair part is defined as the expected number of failures that will occur per year in a group of 100 end items containing the part. Failures that must be considered are those resulting from a deficiency in the inherent reliability of the repair. part (par. **3-34,** as well as those resulting from the application of various K-factors (par. **3-34.** As will be seen, K-factors in addition to those that have been previously discussed are applied in calculating maintenance factors, but the basic principles regarding K-factors versus inherent reliability remain unchanged.

The maintenance factor, because it is an indication of the expected number of failures for a repair part, plays a leading role in many areas of support planning. Its primary use is for provisioning. However, it is also a measure of the anticipated number of corrective maintenance actions that will be performed and, therefore, impacts requirements for all support resources in addition to those that are provisioned. Remembering that materiel life cycle support costs comprise the greater part of materiel life cycle costs, it is apparent that maintenance factors in most cases are the single greatest basic determinant of life cycle costs.

Estimating a maintenance factor is an important task, and procedures have been established with which to accomplish the estimates. However, none of the procedures yet devised can be used without a thorough understanding of the relationship of maintenance factors to other materiel parameters and the significance and source of K-factors. These subjects are discussed prior to the presentation **of** estimating procedures.

5-5.1 MAINTENANCE FACTOR APPLICATION

Although the maintenance factor experiences the greatest amount of usage during initial provisioning, updated versions of the factor are used during the entire life cycle of an item for purposes of resupply. In initial provisioning, the maintenance factor is the key in determining the range and depth of repair part stockage. Also, repair level decisions are influenced by the maintenance factor, with an attempt to insure that the most frequently failing items are easily repaired or replaced at the lowest possible repair level. This, in turn, influences decisions concerning personnel, tool and test equipment requirements, and, consequently, affects training and publications.

Several methods may be used to calculate maintenance factors. These generally can be categorized as the checklist method, math modeling, and automated modeling.

5-5.1.1 Checklist

A checklist is designed to help the analyst think systematically. The aim is to insure that areas which contribute to repair part failures are considered independently in the estimation process. The use of checklists insures that a maintenance factor represents the expected failure rate under a given set of conditions; namely, a given deployment area, given combat conditions, etc. The result of using this approach is a maintenance factor tailored to the situation and conditions that the repair part will experience in deployment, and not one average maintenance factor for some “worldwide” deployment situation.

5-5.1.2 Math Modeling

Math models, which are mathematical representations of real world situations, may be formulated and used to calculate maintenance factors. These are essentially mathematical presentations of checklists. Used manually, these models have little advantage over checklists, but when programmed and used with a computer, they are powerful tools.

The maintenance factors derived from checklists, math models, or other sources serve as inputs to other analytical and dynamic simulation models. Most of these models concern themselves with determining the best placement or allocation of resources such as tools, test equipment, and personnel; as mentioned before, the maintenance factors play a leading role. The analyst, when allocating resources, usually has various objectives in mind pertaining to materiel operational and maintenance parameters; i.e., operational availability, reliability, maintainability, etc. The maintenance factor, representing the failure rate of a repair part, is directly related to these parameters and, in fact, determines their expected values. A maintenance factor "pulled out of the air" or simply not well established can have far-reaching and possibly disastrous effects on the complete support profile of deployed materiel.

Another area of great usage for maintenance factors in the math modeling area is life cycle cost analysis. A large portion of life cycle cost is in logistical and related expenses. In predicting life cycle cost, the number of expected failures for all components and repair parts of a system must be estimated to obtain an idea of logistic requirements. Of course, all other aspects of support, including personnel, test equipment, etc., are contributors to the life cycle cost. These, as mentioned before, also are determined by the magnitude of the maintenance factor.

5-5.1.3 Automated Modeling

Automated modeling involves a general-purpose computer program for the calculation of maintenance factors. Once programmed, the computer will accept inputs in a prescribed format, perform calculations, and provide answers. Inputs may be provided sequentially in a conversational mode, or all at once in a batch mode. Such a computer program is described in AMCP 750-5 (Ref. **6**).

5-5.1.4 Advantages and Disadvantages of Estimating Methods

None of the maintenance factor estimating methods is ideal for all applications. For maximum effectiveness, it is necessary first to consider the task to be done and then to select the most appropriate method for the task. Generally speaking, the method selected will depend upon the magnitude of the task to be accomplished.

The checklist method is time consuming and subject to calculating errors, but it does not require mathematical and computer programming skills and a computer. This method should be used when few items and very few iterations are involved.

The development of math models is also time consuming, and little would be gained by developing math models for manual application unless an extremely great number of iterations is anticipated. However, when used in a computer, math models are very powerful tools that can reduce the risk of human error, as well as providing rapid answers. The most efficient math model to use in a computer would be one that provides for determination of maintenance factors and their subsequent use as dynamic simulation inputs.

Automated modeling reduces the risk of human error, provides rapid answers, and, once the program is written, requires no subsequent programming. It is probably the most efficient estimating method of the three general types that have been discussed.

5-5.2 RELATIONSHIP OF MAINTENANCE FACTOR TO OTHER SYSTEM PARAMETERS

The maintenance factor of a repair part directly affects the availability and reliability of the part and the availability, reliability, and maintainability of the parent end item. The predicted maintenance factor is therefore a very important system parameter and worthy of considerable attention.

5-5.2.1 Relationship to Failure Rate

Failures of a repair part may be categorized as burn-in, random, and wearout. A repair part usually is classified as a random failure part or a wearout part. A random failure part is one that experiences a constant or near constant failure rate during its operational life, and a wearout part is one that experiences an increasing failure rate. Some repair parts experience a decreasing failure rate early in their operational lives, but few sustain such a pattern. Therefore, parts usually are not classified as burn-in failure parts.

At any point in the operational life of a repair part, the majority of failures of a repair part will be due to one of the three types of failures. The failure rate usually is considered to be a constant over a finite period of time representing a portion of the operational life of the part, and reflects the cumulative effect of all types of failures. The estimate of the failure rate will reflect the effects of the three types of failure in light of the usage that was anticipated at the estimation time. The failure rate that the repair part actually experiences in operation in a particular deployment situation may depart from this estimate significantly due to factors that were not considered during the prediction process.

A maintenance factor is nothing more than. a failure rate defined on the basis of 100 end items for a time period of 1 year. Normally, a failure rate is defined on a per-item basis for a period of time. However, the failure rate of an item usually is intended to represent the inherent failure rate and does not take into account any contributing factors such as usage, human error, and environmental effects. In other words, anticipated failures due to burn-in, randomness, and/or wearout are considered the primary sources of failure. The maintenance factor, therefore, is seen to depart from the classical failure rate definition in this way. Namely, the maintenance factor is estimated to represent the failure rate and additional failures brought about by various contributing elements encountered in actual use.

If the maintenance factor is to be of any value for its primary function of estimating the range and depth of repair parts during provisioning, it must be influenced by appropriate parameters. As in the case of reliability where the generic failure rate of an item is factored by the influence of quality, test, usage, etc., to arrive at an operational failure rate, the basic maintenance factor must be influenced by the fact that there is not necessarily a one-to-one relationship between failures and replacements of repair parts. For example, an assembly that is removed, replaced, and subsequently repaired at the organizational level by component replacement would be overstocked if the maintenance factor for the assembly was used for provisioning. Thus, for the establishment of initial provisioning requirements for repairable materiel, the repairable concept and its ultimate impact on repair parts requirements must be considered in addition to the maintenance factor.

5-5.2.2 Relationship to Availability

The maintenance factor representing the failure rate of a repair part is generally assumed to be constant over a finite period of time. For practical purposes, this means that a maintenance factor represents the expected rate of failure for a period of 1 year, allowing for adjustments for future periods of time. The availability of a repair part is directly related to the mean time between failures, which is the reciprocal of a constant failure rate. Therefore, the estimated maintenance factor directly affects the predicted availability of the repair part. This, in turn, contributes to the availability of the end item, which is of primary importance.

5-5.2.3 Relationship to Reliability and Maintainability

The unreliability of a repair part represents the probability of failure of that part in a time increment. Therefore, reliability is a key parameter in maintenance factor determinations. Reliability improvement of a repair part necessitates a reestimation of the maintenance factor.

The relationship of the maintenance factor to the maintainability of a repair part is not as direct, and depends on the particular measure of maintainability used. If the mean downtime, representing total downtime is used, the maintenance factor influences the resupply process by controlling the demand rate for replacement parts and maintenance actions. This, in turn influences the rate at which the repair part is repaired and restored to a usable condition, assuming the repair facility has the capability for repair. If only repair time is used as a measure of maintainability of a repair part, the maintenance factor of that part does not affect the inherent maintainability of the part. The maintainability of the end item/system (inherent or otherwise) is directly affected by the maintenance factors of the member repair parts.

5-5.3 ELEMENTS CONTRIBUTING TO MAINTENANCE FACTOR VARIATION

Since the maintenance factor must reflect failures that are a function of usage and the usage environment, these contributing elements must be considered during the estimation process. The failure of any repair part during usage can be caused by any number of widely diverse factors ranging from operator error to weather conditions. A great number of variables complicates a problem, and complication, in this case, is not warranted since many of the variables cannot be defined precisely. Therefore, six elements have been selected as being the greatest contributors to repair part failures, and these will be examined for their usefulness in making realistic maintenance factor determinations.

To estimate a maintenance factor, the following elements should be considered as possible causes or contributors to repair part failures:

a. Failure rate

b. Usage atmosphere

c. Susceptibility of part to damage

d. Climatic/geographic conditions

e. Utilization rate

f. War vs peace.

The elements in the foregoing listing pose an immediate problem because of possible interactions among the various areas specified. For instance, the usage atmosphere (defined in par. 5-5.5) in reality cannot be isolated completely from the susceptibility of damage to a repair part. In fact, the usage atmosphere could be considered the sole cause of failure, with all the other areas listed as contributing areas within the atmosphere. That is not the intention here, and, by proper definition, it is hoped that the areas listed can be made nearly independent.

It may be seen, from the element definitions in pars. 5-5.4 through 5-5.10, that the failure rate, usage atmosphere, and susceptibility of the part to damage are primarily functions of the design of the repair part or of the design of the end item in which the part is located. The element of climatic/geographic conditions is a function of the environment in which the end item and, therefore, the repair part are expected to be used. The utilization rate and combat conditions are both functions of the actual usage to which the repair part will be exposed in the deployment area.

By classifying the contributing elements in this way, it is possible to define the maintenance factor in a more meaningful and useful manner than before. The maintenance factor can be defined as the expected number of failures of a repair part during a specified time period, resulting from the design, environment, and usage of the part. This definition is conducive to the use of the maintenance factor and is descriptive of the requirements for the estimation process. Based on this definition, the maintenance factor represents all failures that a repair part can experience due to the three areas that can cause repair part failure (i.e., design, environment, and usage). The factor still represents failures expected to occur over a specified time period. This time period can be simply 1 yr, or can be specified as a stockage interval (time between order receipts) in the case of nonrepairable parts, or as the repair/resupply time for repairable repair parts.

5-5.4 FAILURE RATE

Usually, a failure rate is estimated on the basis of reliability test results, past experience, and engineering judgment. The failure rate Value, however, is representative of the number of failures that can be expected for a given item when that item experiences usage that was anticipated in design; i.e., the failure rate will present an idealized rate of failure for the particular item alone. The effects when the item is used in various assemblies, along with other items performing a common function, are not represented, nor are the effects that might be produced by maintenance or operation. As such, the estimated failure rate probably will be determined, in its purest form, by the manufacturer of the item.

Care must be exercised to insure that the manufacturer has not already biased his estimate of the failure rate to take into consideration some stray elements, such as geographic phenomena, which he has anticipated may be encountered in usage. This would be acceptable if the phenomena would always be encountered regardless of the deployment area, but would considerably complicate matters if such conditions only applied to one deployment area. In other words, the contractor's estimated failure rate should include the effects of all conditions met in usage which are to be expected to be met universally.

The failure rate exerts so much influence on the maintenance factor that the importance of thoroughly understanding its basis cannot be overemphasized. Generally speaking, failures in a part will increase as either operating time or stress increases, and will increase even more rapidly if both parameters are concurrently increased. There is a direct relationship between all of the other contributing elements and either operating time or stress. The usage rate is a direct measurement of operating time. All of the other elements contribute to stress. Clearly, the modification of a failure rate that already reflects the effects of one or more of the contributing elements, by those elements, can result in significant maintenance factor errors.

If there is a single, most important step in estimating maintenance factors, probably it is precisely defining the parameters that are used in calculating the failure rate. The rest of the estimation process is based on the assumption that this is accomplished.

5-5.5 USAGE ATMOSPHERE

The usage atmosphere of a repair part is defined, for this discussion, as the makeup (chemical, electrical, etc.) of the physical surroundings of the repair part. As such, it does not include geographic or climatic conditions, but only that part of the physical surroundings that is inherent to the repair part because of the end item design.

The portion of the maintenance factor that is contributed by the usage atmosphere is very similar to that portion identified with the failure rate because it includes failures that are a result of the inherent properties of design. The distinction stems from the fact that very often a repair part is used in many systems in different ways or in performing slightly different functions. For example, a distributor (if classified as a repair part) may be used on many different vehicles with different assembly surroundings. In one vehicle, it may be subject to oil or dust deposits because of its physical location in the vehicle, while in another it may be shielded from such deposits by surrounding components. Such elements definitely affect the maintenance factor of the item, and cannot be accounted for in the contractor's supplied failure rate because all usages of the repair part may not be anticipated at the time of production.

The usage atmosphere also varies somewhat according to the types of .missions. For instance, a repair part in a helicopter will be exposed to different kinds and degrees of vibration and other stresses, depending on whether the mission is an attack mission, a reconnaissance mission, or simply an exercise. Such elements of the usage atmosphere are produced internally although they are a result of an outside agent (i.e., the mission requirements). This area should not be confused with failures induced by combat conditions, which will be discussed later. Naturally, the particular combat conditions to which the repair part is exposed will determine the number and types of missions the part will experience, but it does not determine the effect that a particular action in a mission will have on the part. This effect will be considered under usage atmosphere, while the cause, frequency of occurrence, and duration will be considered under the combat conditions element.

Some items to consider in the usage atmosphere area are exposure of the repair part to vibration, chemicals, oil, electrical and magnetic fields, radiation, and system generated heat or cooling. In other words, any conditions internally produced by operation of the system must be considered. These elements must be analyzed with respect to the design of the repair part, and the analyst must keep in mind that the failure rate previously discussed will reflect any failures contributed by the usage atmosphere that has been anticipated in design.

5-5.6 SUSCEPTIBILITY OF PART TO DAMAGE

Through handling, installation, and maintenance, a part is exposed to varying degrees of probability of damage. This is due to human error/skill as well as design, and is independent of the failure rate of the repair part. It could be thought of as the "accident rate" of the part. A good example is an electronic part destroyed by the heat of the soldering iron during installation. To help insure independence between this contributing factor and others (e.g., the usage atmosphere), this factor has been defined only for handling, installation, and maintenance. For example, if, during use, a very fragile part is destroyed by vibration (internally or externally), the failure must be attributed to the usage atmosphere (internal vibration) or the climatic/geographical conditions (external vibration).

A part can be damaged through handling while being transported or installed on a system, or during storage. At the time of installation, the part also may be damaged by the installation equipment. When preventive maintenance is performed on the part, or when corrective maintenance is performed on nearby or functionally related parts, damage may also occur. This is especially true of parts that must be removed for access to other failed items. Any possibility of damage during testing also must be considered. Many parts require periodic adjustments if they are to function properly, and such parts may be damaged by improper adjustments or if they are used while they are improperly adjusted. All these areas would be a part of this contributing element and must be considered during the analysis.

Since damage or failures resulting from this contributing factor are functions of human error and design, the level of competence of maintenance personnel plays a large role. This requires the analyst to be familiar with the maintenance personnel who will be working with the particular repair part. Also, the maintenance factors of surrounding parts must be considered because of the chance that a failure may be produced while maintenance on another part is performed.

5-5.7 CLIMATIC/GEOGRAPHIC CONDITIONS

Possible damage or deterioration of a repair part due to the climatic or geographic conditions to which it will be exposed is considered in this area. Climatic/geographic conditions make up that part of the repair part environment which is uncontrolled or uncontrollable by the user.

The effects of temperature, temperature changes, and humidity are the most obvious areas to consider. However, other areas such as exposure to dust, abrasives, moisture, and altitude (barometric pressure) must be considered. In addition, the natural geographic and manmade features of the deployment area (terrain) play a role in producing failures during operation. For example, some deployment areas have very good roadway systems with bridges and other manmade features that considerably affect the operation of an end item and the stress levels applied to the repair part. On the other hand, the same end item would be used differently and have different stresses applied to it in less developed areas. This would also depend upon the natural geographical features in the area. Indeed, there are so many different conditions that can change from one deployment area to another that this element alone, contributing to failures, will necessitate tailoring a maintenance factor for each deployment area.

Par. **3-4.3.1** provides many examples of the effects of various climatic/geographic conditions on materiel. Par. **3-4.8** elaborates on corrosion and corrosion-preventive finishes. The effects of climatic/geographic conditions on the failure rate of a repair part are not included in contractor supplied failure rates unless the repair part has been designed for a particular geographic area. Therefore, the effects of climatic/geographic conditions must be analyzed with respect to the design parameters of the repair part. Quite often, items intentionally are designed to withstand certain climatic conditions, or are composed of materials that are not affected adversely by certain climatic or geographic conditions. In such cases, the failure rate determined by the contractor would be assumed to account for failures contributed from such causes because it is part of the design.

5-5.8 UTILIZATION RATE

The use that the repair part experiences influences the rate at which failures will occur in a group of such items. The utilization of a repair part is expressed in the same terms as the utilization of the system that contains the part. This may be hours of use, rounds fired, or miles traveled, but nevertheless represents the amount of use the system and hence the repair part has experienced.

In estimating a maintenance factor, the utilization rate of the repair part must be predicted. The utilization rate will change according to the deployment areas, and the prediction can be done on the basis of past experience, mission plans, and requirements of the deployment area.

There is a-possibility that a repair part may experience deterioration because of lack of use. In such cases, the manufacturer is expected to supply information concerning the required usage to keep the part from deteriorating. This would also have to be considered in reference to the predicted utilization rate in predicting the maintenance factor.

Normal use would not be expected to contribute significantly to the failure rate because normal use is assumed in arriving at the estimated failure rate of the repair part. Extreme usage (i.e., for extended periods of time or usage under stress or strain), however, would contribute to failures and would be included in the utilization rate element of the maintenance factor. Another aspect that should be considered under this element is any possible failure that may be induced by the operator of the end item that contains the repair part under analysis. This requires the analyst to be familiar with the types and skill levels of the personnel who will be operating the equipment.

5-5.9 WAR VS PEACE

The military condition of the deployment area substantially affects the maintenance factor. In a wartime environment, the maintenance factor must reflect the failures resulting from intense and extreme usage, the relative neglect of maintenance that occurs because of the pressures of combat, and combat damage of parts and assemblies that are prone to damage from mines, fragments, and small arms fire. Catastrophic loss of complete end items is not included. However, if the item is deployed in a predominantly peacetime environment, provisioning based on a wartime maintenance factor will result in overstockage of repair parts. Because of the diversity in conditions between war and peace, efficient provisioning dictates a requirement for two maintenance factors–one for peacetime and one for wartime.

5-5.10 DETERMINATION OF MAINTENANCE FACTORS BY THE CHECKLIST METHOD

Six elements have been defined as contributors to the value of the maintenance factor (i.e., failure rate, utilization rate, combat conditions, climatic/geographic conditions, usage atmosphere, and susceptibility to damage). **A** checklist–Appendix A located at the end of the chapter–has been devised to insure that each element shall receive proper consideration when maintenance factors are calculated. The paragraphs that follow describe the checklist and the way in which it is to be used.

5-5.10.1 Checklist Description

The checklist provides a systematic sequence of data collection points, questions, and instructions to guide an analyst in calculating a maintenance factor for a given set of conditions. For each change in conditions, a new' estimate must be made. Although use of the checklist procedures requires no training, its use should not be attempted by other than experienced maintenance engineering personnel because of the subjective nature of many of the required activities.

5-5.10.2 Estimation Guidelines

It cannot be overemphasized that the estimation process should be made on the basis of the total environment of the repair part under consideration. The task is extremely difficult when only drawings are used because of the difficulty of visualizing a total, completed system or end item. Therefore, it is strongly recommended that the final maintenance factor estimate be made by analyzing the repair part while it is physically positioned on a prototype or end item. Only then can all factors influencing the failure rate be integrated into a total analysis to measure interactions that must be anticipated in the maintenance factor estimation.

Since the maintenance factor experiences considerable usage during initial provisioning, it is essential that the factor be accurate, since over- or underprovisioning may result. Therefore, the process of phased provisioning may be worthwhile in instances when there is reason to believe that the maintenance factor is not accurate.

To use the checklist, the analyst must start with the first question and proceed through all the questions. Answering questions out of sequence is permissible only when stated at the individual questions. Several questions appear to be asked with no apparent use for the answers. The purpose of these questions is merely to get the corresponding answers into the mind of the analyst. Answers to following questions depend on how the analyst answers such questions in his own mind, and these apparently meaningless questions cannot be overlooked or disregarded. Some of the questions are to be answered "Yes" or **"No".** Whenever any question is answered "No", the analyst should go to the next numbered question.

In several questions, the analyst must estimate the number of failures due to some condition. The method of estimation is left to the analyst and his judgment. In making such estimates, the analyst must put everything out of his mind except the particular condition being viewed to insure that the estimate represents only the condition being analyzed. Otherwise, the total maintenance factor will represent more failures than expected because some conditions will be accounted for several times. This may be difficult to do, but the checklist is designed to aid this process.

The analyst must go through the checklist twice for each deployment area—one iteration for peacetime conditions and one iteration for wartime conditions.

5-5.10.3 Cautionary Note

The casual reader must be cautioned. This checklist does not supply any answers of its own. No data are incorporated relating past experience, like equipment, or the effects of any conditions. The analyst is expected to be an authority on such subjects, and experience has shown that maintenance factors estimated in the past have been reasonably accurate in the initial estimate. This lends support to the qualifications of analysts.

The questions contained in the checklist are self-explanatory; therefore, no further explanations are provided.

5-5.11 MAINTENANCE FACTORS DETERMINED BY MATHEMATICAL ANALYSIS

It may be seen from the preceding discussion concerning the determination of maintenance factors by the checklist method that such calculations are tedious and time consuming. Calculations must be performed for peacetime and wartime conditions, for each deployment area and for each item, so that the required number of calculations can become quite large. Additionally, the probability of making errors in repetitive operations is great and the time required to make the calculations not only costs money, but also delays decisions.

Mathematical analysis is an alternative to the checklist. This approach, coupled with the use of a computer, involves the initial expenditure of time to develop and program a math model, but subsequently requires minimum analyst time and modest computer costs.

5-5.11.1 Typical Mathematical Formulas

The Army Materiel Command has developed the FORTRAN variables list and formulas that follow for calculating peacetime and wartime maintenance factors for each deployment area and for calculating overall maintenance factors for peacetime and wartime. Details of a computer program that uses the variables and formulas are contained in Ref. 6.

a. FORTRAN Variables List

I = 1,2, ..., 5		(deployment area)
J = 1,2		peacetime = 1, wartime = 2
K = 1,2, ..., 8		usage or climatic condition
FR	=	manufacturer's predicted mean time between failure
FRMF (I, J)	=	operating hours, miles, rounds/end item/year
RNP	=	number of parts/assembly
SUFR (I, J)	=	part failures/assembly/year due to severe usage
OPE (I)	=	mean time between failures of repair part due to operator error
CFR (I, J)	=	on-off cycles/end item/year
CPF	=	number of cycles/failure
RIFR (J)	=	part failures/assembly/year due to idleness
CGMF (I, K)	=	part failures/assembly/year due to climatic geographic effects
UMF (K)	=	part failures/assembly/year due to surrounding equipment and parts
CDF (J)	=	part failures/aSsembly/year due to combat damage
PMFR	=	part failures/assembly/year due to preventive maintenance
RFR	=	part failures/100 part installations during corrective maintenance
STFR (I, J)	=	% parts failing in storage
TSFR (I, J)	=	% parts failing in transportation and handling
NA	=	number of deployment areas (maximum of 5 areas)
AREA (I)	=	name of area (6 characters maximum)
PNAME (4)	=	part name (24 characters maximum)

FSN (6)	=	part number (18 characters maximum)
EIN (4)	=	end item name (24 characters maximum)
OMF (J)	=	previous maintenance factor
IUSE	=	usage code (1 = hours, 2 = miles, 3 = rounds)
ANAME (4)	=	assembly name (24 characters maximum)

(Climatic/Geographic Conditions Considered)

CGMF (I, 1)	=	temperature extremes
CGMF (I, 2)	=	temperature changes
CGMF (I, 3)	=	humidity
CGMF (I, 4)	=	moisture
CGMF (I, 5)	=	altitude
CGMF (I, 6)	=	abrasives
CGMF (I, 7)	=	dust
CGMF (I, 8)	=	other agents

(Usage Atmosphere Conditions Considered)

UMF (1)	=	electric fields
UMF (2)	=	magnetic fields
UMF (3)	=	vibration
UMF (4)	=	heat
UMF (5)	=	cold
UMF (6)	=	chemicals
UMF (7)	=	radiation
UMF (8)	=	other agents

b. Formulas.

X_{ij} = maintenance factor for deployment area i for peacetime or wartime without considering part failures due to corrective maintenance, storage, or transportation.

$$X_{ij} = 100\,[\,FRMF_{ij}(RNP/FR + 1/OPE_i) + SUFR_{ij} + (CFR_{ij}RNP)/CPF + RIFR_j + \sum_{K=1}^{N} CGMF_{iK} + \sum_{K=1}^{N} UMF_K + PMFR + CDF_j\,] \tag{5-1}$$

Y_{ij} = maintenance factor for deployment area i for peacetime or wartime (adjusted for corrective maintenance failures).

$$Y_{ij} = X_{ij}(1 + RFR/100) \tag{5-2}$$

MF_{ij} = maintenance factor for deployment area i for peacetime or wartime (adjusted for storage and transportation failures).

$$MF_{ij} = Y_{ij}\{\,1/[\,1 - (TSFR_{ij} + STFR_{ij})/100\,]\,\} \tag{5-3}$$

MF_j = Overall average maintenance factor for peacetime or wartime, indicated by $j = 1$ or $j = 2$, respectively.

$$MF_j = \frac{\sum_{i=1}^{NA} MF_{ij}}{NA} \tag{5-4}$$

5-5.1 1.2 Use of Formulas

In use, the formulas would be programmed, and the program entered into a computer. Subsequently, the maintenance engineering analyst calculating maintenance factors would simply fill out a loading form comprised of sheets similar to the one shown in Fig. 5-7. Computer personnel would keypunch cards showing these data and enter the data into the computer, and the required maintenance factors would be calculated and printed. Clearly, this automated method is much to be desired over the checklist.

In a major materiel program, it might be economical to make the foregoing computer program a subroutine to a larger program that would apply the maintenance factors to the calculation of maintenance actions and support resource requirements at the several maintenance levels. Such an overall program would permit immediate determination of the compatibility between estimated maintenance factors and planned support resources.

LINE NO.	VARIABLE DESCRIPTION	DATA				
	(In lines 25 thru 43 data elements under areas not being considered must be left blank while data elements under areas being considered must have a value, even if it is zero.)	Area 1	Area 2	Area 3	Area4	Area 5
	Operating Hours, Miles, Rounds/End Item/Year					
25	Peacetime					
26	Wartime					
	Part Failures/Assembly/Year Due to Severe Usage					
27	Peacetime					
28	Wartime					
	ON-OFF Cycles/End Item/Year					
29	Peacetime					
30	Wartime					
	% Fail in Transportation and Handling					
31	Peacetime					
32	Wartime					
	% Fail in Storage					
33	Peacetime					
34	Wartime					
	MTBF/Repair Part Due to Operator Error					
35						
	Failures/Assembly/Year Due to Climatic Geographic Effects					
36	Temperature Extremes					
37	Temperature Changes					
38	Humidity					
39	Moisture					
40	Altitude					
41	Abrasives					
42	Dust					
43	Other Agents					

Figure 5-7. Sample Form for Use in Loading Data

APPENDIX A. MAINTENANCE FACTOR CHECKLIST (Ref. 6)

APPLICATION IDENTIFICATION

1a. Record, below, the nomenclature of the system/end item of equipment that contains the repair part under consideration.

____

b. Record, below, the nomenclature of the next higher assembly that contains the repair part under consideration.

____

c. Record, below, the nomenclature or other identification (part number, SIN) of the repair part under consideration.

____

d. For the repair part in question, write, below, the number of these parts contained in the next higher assembly.

____________ parts/assembly

FAILURE RATE

2. Write, below, the manufacturer's predicted failure rate for the repair part being analyzed, or the failure rate obtained through testing. Miles driven, rounds fired, etc., may be substituted directly for "operating hour".

________ failures/operating hour

3. For the deployment area under consideration, what is the expected number of operating hours per year that the repair part will be used (same as parent end item).

________ operating hours/year

4a. Multiply the answer to **2** by the answer to **3.**

________ failures/part/year

b. Multiply the answer to 4a by the answer to 1d.

________ failures/assembly/year

5. If the repair part has a maintenance factor, list that factor below.

________ maintenance factor = failures/assembly/100 end items/year

6a. List the conditions that have been accounted for in the failure rate listed in **2,** or the maintenance factor listed in 5 (i.e., all conditions or effects that have been considered in the estimate of the failure rate, or previous maintenance factor).

b. The following questions have been designed to determine the various effects that may already be accounted for to some extent in the manufacturer's estimated failure rate or a previously defined maintenance factor. If such effects have been included in previous estimates, this should be remembered when the question or questions are reached which contain the estimation process for the effects mentioned. This will help guard against duplicating work and including causes of failures more than once in the estimated maintenance factor.

c. Any question below that is answered "Yes" must be analyzed to insure that all conditions included in the initial estimate of the failure rate are kept in mind during the following estimation process. It is recommended that all such conditions be listed and kept on hand while the questions in the following sections are answered.

APPENDIX A. MAINTENANCE FACTOR CHECKLIST (Cont'd)

FAILURE RATE (Cont'd)

d. A previously estimated maintenance factor will not be used to estimate a new one, but will be used for comparison purposes.

e. Utilization Rate:

YES NO 1. Was severe usage considered in initial estimate?

YES NO 2. Was cyclic operation considered in initial estimate?

YES NO 3. Was deterioration due to idleness taken into consideration?

f. Combat Considerations:

YES NO 1. Was the initial estimate of the failure rate based on any particular combat posture, or did it allow for any combat effects?

YES NO 2. Was repair part designed for a particular level or kind of combat?

g. Climatic/Geographic Conditions:

YES NO 1. Were any effects such as temperature extremes, temperature changes, humidity, moisture, altitude, abrasives, dust, or other climatic/geographic condition taken into account in the initial estimate of the failure rate?

YES NO 2. Is the failure rate received from the contractor estimated for a particular geographic or climatic area?

h. Usage Atmosphere:

YES NO Were an37 effects such as vibration, heat, cold, chemicals, electric fields, magnetic fields, and radiation taken into account in the initial estimate?

1. Susceptibility to Damage:

YES NO Were possible failures that may result from adjustments made on repair part during preventive maintenance considered in the initial estimate?

UTILIZATION RATE

7. YES NO a. Is the repair part likely to encounter severe usage in the area under consideration? (Severe usage will be interpreted as any usage that exceeds design limitations or will exert extreme stress on the part.)

b. What percentage of operation time will repair part experience severe usage?

________ % severe usage time

c. In light of answer for 7b, how many estimated failures per year will this produce?

________ failures/assembly/year

APPENDIX A. MAINTENANCE FACTOR CHECKLIST (Cont'd)

UTILIZATION RATE (Cont'd)

8. YES NO

a. Considering the technical ability of operating personnel who will be operating the equipment, and the skill level required for successful operation, is it possible that the repair part can be damaged by operator error or misuse?

b. Again considering the ability of operating personnel in reference to operating skill requirements, how many estimated failures per operating hour will this produce?

NOTE: Consider climatic/geographic effects on operator ability also.

_______ failures/operating hour/assembly

9. YES NO

a. Is cyclic operation likely to cause undue stress on the repair part which will contribute to failure?

YES NO

b. Will repair part encounter cyclic operation (characterized by repeated stopping and start, startup or shutdown, etc.)?

c. What is the expected number of cycles (start and stops, etc.) that repair part will experience per year?

_______ cycles/year

d. If the manufacturer provides guidance concerning the expected number of cycles the repair part can withstand, indicate the manufacturer's suggestion.

_______ cycles/failure

e. Estimate the number of failures that will occur on a per-cycle basis. (This will be from paragraph 9d if available; otherwise, estimate.)

_______ failures/cycle

f. Multiply answer to 9c by answer to 9e.

_______ failures/part/year

10. YES NO

a. Will repair part deteriorate during storage or during prolonged periods of idleness?

b. Considering that the average repair part will be stored in inventory for a period of time equaling one-half of the stockage period (or stockage objective), estimate the number of failures per assembly per year that will result from deterioration.

_______ failures/assembly/year

c. Considering the mission goals and requirements, if it is likely that the repair part will experience periods of idleness during its usage life that will adversely affect it, estimate the number of failures per assembly per year that will result from such idleness.

_______ failures/assembly/year

UTILIZATION RATE (Cont'd)

11. Multiply the answer to 8c by the answer to **3.**
    ________ failures/assembly/year
12. Multiply the answer to 9f by the answer to 1d.
    ________ failures/assembly/year
13. Add the answers to 7c, 10b, 10c, 11, and 12.
    ________ total failures/assembly/year due to utilization rate

COMBAT DAMAGE

14. For a wartime environment, estimate the failures per assembly per year of the repair part under consideration caused by combat damage. Failures resulting from catastrophic loss of the next higher assembly or entire end item should not be considered. If a peacetime maintenance factor is to be determined, enter zero.
    ________ failures/assembly/year due to combat damage.

CLIMATIC/GEOGRAPHIC CONDITIONS

15. Is repair part likely to be damaged by continuous exposure to climatic/geographic controlled:
    YES NO a. Temperature (extreme heat and/or cold)
    YES NO b. Temperature changes
    YES NO c. Humidity
    YES NO d. Moisture
    YES NO e. Altitude (barometric pressure)
    YES NO f. Abrasives (e.g., sand)
    YES NO g. Dust
    YES NO h. Other agents
16. YES NO a. For items answered "Yes" in 15, are any of these agents likely to be encountered in the deployment area?
    b. Check in Table A-1, column A, the agents in 15 that will be encountered in the deployment area.
    c. Keeping in mind the natural and manmade climatic/geographic conditions in the deployment area, specify whether the agents checked in Table A-1, column A, will be encountered to the degree that would hamper the mission capability of the repair part or possibly contribute to failure of the repair part (indicate answer in Table A-1, column B).

CLIMATIC/GEOGRAPHIC CONDITIONS (Cont'd)

d. For the agents that are marked "Yes" in column B, estimate the percentage of total operating time that repair part will be exposed to the agent to a degree that could contribute to failure. Record this percentage in Table A-1, column C.

e. List in Table A-2, column A, those agents marked "Yes" in Table A-1, column B, in descending order according to the "% of time exposed". In the "Relative Weight" column (column C), weight the agents listed on a scale from 1 to 10 according to the degree of influence the agent is expected to have on the failure rate of the repair part (i.e., the agent that will least affect the failure rate would be assigned a weight of 1 while the agent with the most effect would be assigned a 10, with all other agents assigned intermediate values).

f. Multiply the "% of time exposed" (Table A-2, column B) by the "Relative Weight" (Table A-2, column C) for each agent listed in 15e, and enter result in Table A-2, column D.

g. List agents specified in Table A-2, column A, in Table A-3, column A, in descending order according to the "Product" in Table A-2, column D. This will represent the order in which agents that are a function of climatic/geographic conditions will be expected to cause failures of the repair part.

h. For agents listed in Table A-3, column A, estimate the number of failures per year that you would attribute to the climatic/geographic agent. Record result in Table A-3, column B.

17. Sum the values listed in Table A-3, column B, and enter result below.

________ total failures/assembly/year due to climatic/geographic conditions

USAGE ATMOSPHERE

18. Is repair part likely to be damaged by:

YES NO a. Vibration (frequency and amplitude)
YES NO b. Heat
YES NO c. Cold
YES NO d. Chemicals
YES NO e. Electric fields
YES NO f. Magnetic fields
YES NO g. Radiation
YES NO h. Other agents (e.g., coolant leakage)

USAGE ATMOSPHERE (Cont'd)

19. YES NO a. For items answered "Yes" in 18, are any of these agents produced by surrounding parts or by the parent system, or will repair part be exposed to agents in 18 from any outside source other than climatic/geographic sources?

b. List in Table A-4, column A, agents to which the repair part will be exposed, that also have been answered "Yes" in 18.

c. For each agent listed in Table A-4, column A, evaluate anticipated exposure of repair part in reference to manufacturer's suggested tolerance levels.

d. Considering the number of operating hours per year, estimate the number of failures per assembly per year for the repair part caused by each of the agents listed in Table A-4, column A.

20. Sum the values listed in Table A-4, column B, and enter result below.

_______ total failures/assembly/year due to usage atmosphere

21. List the answers (total failures due to _______) due to all elements considered thus far. These answers are found in 4b, 13, 14, 17, and 20.

_______ failures/assembly/year due to failure rate

_______ failures/assembly/year due to utilization rate

_______ failures/assembly/year due to combat damage

_______ failures/assembly/year due to climatic/geographic conditions

_______ failures/assembly/year due to usage atmosphere

22. Sum the numbers listed in 21, and enter result below.

_______ failures/assembly/year due to all effects except susceptibility

SUSCEPTIBILITY TO DAMAGE

23. YES NO a. Is the repair part fragile or conducive to failure by handling during transportation or storage?

b. Estimate transportation time to the deployment area and storage time the repair part will experience from the time of manufacture to installation (in years).

(1) _______ transportation time

(2) _______ storage time

c. With the answer to 23a and 23b in mind, estimate the number of failures that are expected to occur for the repair part during the times given in 23b.

(1) _______ failures during transportation time

(2) _______ failures during storage time

SUSCEPTIBILITY TO DAMAGE (Cont'd)

d. If the transportation time and/or storage time in 23b is greater than 1 year, convert the answers to 23c to failures per year by dividing answers by the two corresponding times.

(1) _______ failures/year due to transportation

(2) _______ failures/year due to storage time

e. Add the answers to 23d together and multiply the results by the answer to 1d.

_______ failures/assembly/year due to handling

24. YES NO a. Does repair part require preventive maintenance, and if so, are adjustments made or tools and test equipment used that may damage repair part and thus induce failures?

b. List frequency of preventive maintenance actions in terms of actions per assembly per year.

_______ preventive maintenance actions per year

c. Keeping in mind the criticality of adjustments, skill levels of personnel, and the effects of climatic/geographic conditions on personnel performance, tools, and test equipment used, how many failures do you estimate will result from 100 preventive maintenance actions?

_______ failures/100 preventive maintenance actions

d. Multiply answers to 24b and 24c and divide by 100.

_______ failures/assembly/year due to preventive maintenance

25. YES NO a. Keeping in mind the skill level of the maintenance personnel, climatic/geographic effect on personnel performance, and the tools and test equipment used during installation, can failures of the repair part be induced during installation of the part on the parent assembly?

b. In reference to 25a, during 100 installations of the repair part, how many failures do you estimate will result? This represents probability of failure by installation damage.

_______ failures/100 installations

c. Divide answer to 25b by 100

_______ probability of failure during installation

d. Add answers to 22 and 24d

_______ failures/assembly/year

e. Multiply answer to 25c by answer to 25d

_______ failures/assembly/year due to installation

26. Add answers to 23e, 24d, and 25e.

_______ total failures/assembly/year due to susceptibility

COMPUTATION OF TOTALS

27. List below and total the answers to 22 and 26.

Answer to 22 = ________ failures/assembly/year

Answer to 26 = ________ failures/assembly/year

Total = ________ failures/assembly/year

28. Multiply the total part failures per assembly per year found in **27** by 100 and record this value in the appropriate column of Table A-5. This is the maintenance factor expressed in failures per assembly per 100 end items per year. (When the assembly is unique, this is equivalent to failures per 100 end items per year.) Return to **3** of the checklist if a peacetime estimate and a wartime estimate have not been completed for each deployment area; otherwise, proceed to 29.

29. An average peacetime or wartime maintenance factor may be obtained by summing column A or B, respectively, of Table A-5 and dividing the total by the number of areas being used.

TABLE A-1. CLIMATIC/GEOGRAPHIC AGENTS

A AGENT LIST (2.b)	X	B YES	 NO	C % OF TIME EXPOSED
Extreme Temp.				
Temp. Changes				
Humidity				
Moisture				
Altitude				
Abrasives				
Dust				
Other				

TABLE A-2. RELATIVE WEIGHT

A AGENT LIST	B % OF TIME EXPOSED	C RELATIVE WEIGHT	D PRODUCT (B x C)

A AGENT LIST	B FAILURES/YEAR

TABLE A-4. USAGE ATMOSPHERE FAILURES

A AGENT LIST	B FAILURES/YEAR

TABLE A-5. MAINTENANCE FACTOR RESULTS

AREA	AREA NAME	A PEACETIME MF	B WARTIME MF
1			
2			
3			
4			
5			
	SUM →		

$$\text{Average peacetime MF} = \frac{\text{Sum peacetime MF}}{\text{Number of areas}} = \_\_\_\_\_\_\_\_$$

$$\text{Average wartime MF} = \frac{\text{Sum wartime MF}}{\text{Number of areas}} \_\_\_\_\_\_\_\_$$

REFERENCES

1. MIL-STD-1388-1, *Logistic Support Analysis,* 15 October 1973.
2. USAMC DI-S-1825, *Preliminary Maintenance Allocation Chart (PMAC),* 15 December 1969.
3. USAMICOMR 750-8, *Generation and Processing of Preliminary Maintenance Allocation Charts and Tool and Test Equipment Lists,* 16 March 1972.
4. USTACOM SOP 700-3A, *Preliminary Maintenance Allocation Chart (PMAC),* 7 August 1972.
5. MIL-STD-1388-2, *Logistic Support Analysis,* 15 October 1973.
6. AMCP 750-5, *Objective Determination of Maintenance Factors (Draft),* June 1974.
7. AMCP 750-XX, *AMC Guide to Logistic Support Analysis (Draft),* May 1974.

BIBLIOGRAPHY

AR 310-3 C5, *Preparation, Coordination and Approval of Department of the Army Publications,* 4 October 1971.

TM 38-715-1, *Provisioning Techniques,* October 1965.

CHAPTER 6
TESTING, DEMONSTRATION, AND EVALUATION

This chapter addresses the test, demonstration, and evaluation activities that occur during a materiel life cycle testing program. Development and operational tests, maintainability demonstrations, and maintenance evaluations are discussed. Mathematical analysis techniques useful in test planning and analyzing test results are described.

6-1 INTRODUCTION

Testing, demonstration, and evaluation include joint, integrated tests of materiel and the support subsystem, tests specifically conducted to verify the support subsystem, maintainability, reliability, etc., and all efforts associated with maintenance evaluation. All of these activities involve the use of materiel, and parts or all of a support subsystem, and produce information required to validate the adequacy of support planning and materiel design. Stated another way, they provide data with which to validate and refine existing maintenance engineering analysis data.

Test, demonstration, and. evaluation data are of vital importance to maintenance engineering. The interactions between materiel design and the support subsystem, and between various resources within the support subsystem are too complex to be determined with a high degree of confidence by analysis alone. This statement applies in particular to new materiel. Maintenance times, failure rates, skill requirements, test equipment, technical manual requirements, etc., can all be predicted by reliability, maintainability, and maintenance engineering analyses, but the analyses must be validated and refined with test data on an iterative basis to permit logical progression toward a production configuration.

Maintenance engineering analysis, materiel and support subsystem design, and test, demonstration, and evaluation form a closed loop system as shown in Fig. **6-1.** Maintenance engineering analysis data, initially predicted, impact the design of the materiel and of the support subsystem. The materiel and subsystem are subjected to tests and the test data are used to update the maintenance engineering analysis data. The new data may generate changes in materiel and support design, new tests may be conducted, and these tests provide additional engineering analysis data, etc. This process starts with the availability of mock-ups or breadboard hardware in the development phase and continues through the deployment phase.

The data received from tests, demonstrations, and evaluations augment maintenance engineering analysis data obtained from historical records and from currently deployed materiel. The total process, properly performed, is necessary for the attainment of the goal of the integrated logistic support concept, which is to take necessary actions during a materiel acquisition cycle to insure the effective and economical support of materiel at all levels of maintenance for its programmed life cycle. The iterations provide a management tool that permits management control of the technical aspects of integrated logistic support. Maintenance engineering issues requirements that impact both design and the support subsystem. The tests use hardware and software that are supposed to satisfy the requirements. Observation of the tests and analysis of the resulting data immediately demonstrate the degree to which the original requirements have been satisfied, as well as demonstrating current deficiencies that must be eliminated.

6-1.1 SUPPORT TESTING (Ref. 1)

The evaluation of a support subsystem commences with development and extends into the deployment phase. The evaluation process includes the accomplishment of various types of tests and demonstrations. The paragraphs that follow describe the tests and the types **of** information that can be obtained as materiel progresses through its life cycle. The discussion is largely generic in nature and is devoted exclusively to support. This should not be construed to mean that all of the testing is devoted exclusively to the support subsystem. **As** previously stated, some of the tests are integrated. For convenience, the test types are categorized numerically.

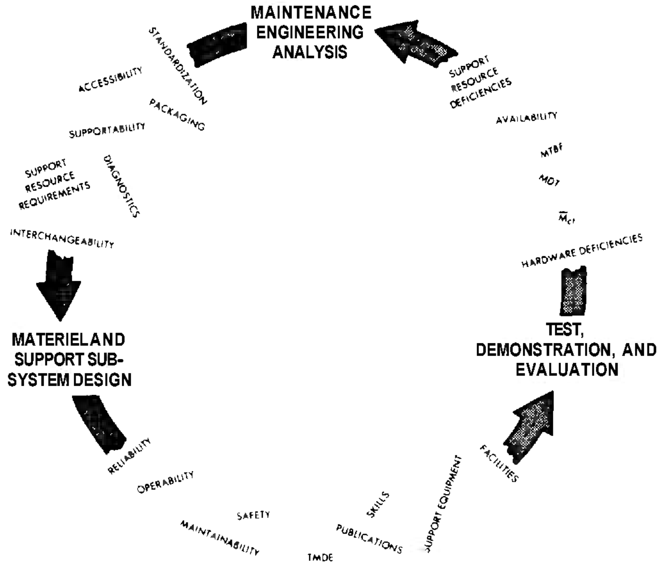


Figure 6-1. Maintenance Engineering Analysis, Design, and Test Cycle

6-1.1.1 Category I—Tests/Demonstrations

Category I tests are informal breadboard, brassboard, or prototype development model tests conducted by the developer, with customer surveillance, on an as-required basis. The tests are accomplished throughout equipment design, development, and qualification. Although the tests are not formal demonstrations and do not reflect production equipment in a true operational environment, resulting information pertinent to logistic support characteristics is used to update preliminary maintenance engineering analysis data. Some of the testing activities include equipment operational and logistic support actions that are directly comparable to tasks performed in an operational requirement. Data covering these activities are evaluated in terms of operational, maintenance, and support parameters. It is during this initial phase that changes to hardware design/configuration can be readily and economically made to eliminate or reduce the need for performing maintenance or operational actions.

6-1.1.2 Category II—Tests/Demonstrations

Category II tests are formal tests and demonstrations accomplished during the latter part of the development phase on preproduction prototype equipment that is similar to production equipment but not necessarily fully qualified at that point in time. The tests generally are conducted by the developer at his facility, with customer on-site surveillance. Operational support equipment (or equivalent) and preliminary technical manuals are used for test support. The specific types of tests include formal maintainability demonstrations, support equipment compatibility tests, personnel tests and evaluation, and technical manual verification/validation. The test data are analyzed to determine whether or not the equipment design/configuration can be changed to eliminate maintenance requirements and if the support subsystem does, in fact, satisfy the maintenance requirements.

6-1.1.3 Category III—Tests/Demonstrations

Category III tests are formal tests and demonstrations accomplished prior to large-scale production commitments on pilot or initial production materiel. The tests are conducted by customer personnel at the customer's test site. Developer personnel provide certain predefined on-site support. Operational support equipment, operational spares, and formal technical manuals are used. Field test data are collected and analyzed to determine whether or not the equipment design meets all maintainability and maintenance quantitative requirements. This is the first time that all elements of the system (materiel and support subsystem) are operated and evaluated as a total entity. Here is the first opportunity to assess total system design from a support standpoint, as well as to assess the support subsystem in terms of specific support requirements, shop turnaround times, supply pipeline times, etc.

6-1.1.4 Category IV—Tests/Demonstrations

Category IV tests are formal tests and demonstrations of the total operational system and its associated support subsystem conducted in a true field operational and maintenance environment. Customer personnel, operational facilities, operational support equipment, repair parts, and technical manuals are used. Formal field data reporting systems provide the data necessary for support system evaluation and assessment.

6-1.1.5 Data Analysis and Corrective Action

The data resulting from logistic support testing must be analyzed in such a fashion that the results of the analysis reflect preplanned corrective actions correlated to program contingency planning. This requires that data analysis must be preplanned in an organized, documented, systematic fashion prior to the conduct of the testing.

Category I test data analysis and corrective actions must be tailored only to those characteristics of systems support that informal breadboard or prototype development model type testing can investigate. This applies to those support considerations predicated on correlated reliability and maintainability design features; i.e., redundancy concepts, repair-while-operating considerations, built-in test levels, modularity, commonality, etc. The feedback resulting from this testing is directed toward the support concept.

Category II test data analysis and corrective actions are tailored to form, fit, and maintenance characteristics of systems that directly affect on-line support considerations. The feedback resulting from analysis of these data is planned to confirm or modify support equipment, technical manuals, personnel requirements, and maintenance and supply burdens. It also should give preliminary validation to organizational level support concepts.

Category III test data analysis and corrective action loops are tailored to verify the system performance and support in the operational environment. They further substantiate the assumed reliability and maintainability characteristics on which the support concept is predicated and give formal assessments to off-line maintenance requirements, as well as preliminary validation and correction. They add to the provisioning and higher echelon (depot and contractor) support validations.

Except for Category IV test data analysis and corrective actions, the total support subsystem cannot truly be tested or validated. However, by judicious test planning and design, the characteristics of the system which affect the corrective actions required at each point in the life cycle can be identified. The program manager must specify data requirements and analysis procedures appropriate to those corrective actions, while also constantly building up confidence in the overall support concept and its quantitative requirements.

6-1.1.6 Design of Support Test Program

The extent of formal support testing/demonstrations accomplished must be tailored to the:

a. System/equipment type: specific end item, aircraft, missile, electronic, vehicle, etc.

b. System configuration in terms of new development versus the use of an off-the-shelf capability. New development might introduce high risk that influences testing requirements,

c. Mission objectives and operational/support requirements of the system in terms of quantitatiye figures of merit such as system effectiveness, operational availability, reliability, and downtime.

The basic objective is to accomplish only that testing required at discrete points in the system acquisition process to gain confidence that the system or equipment will ultimately meet the mission and associated operational requirements for which it was intended. Too much testing is costly. Too little testing does not provide the confidence needed early in the acquisition cycle to determine whether or not the system will meet its design requirements. The wrong type of testing is also costly and will not provide worthwhile or meaningful results.

As a general rule of thumb, it may be stated that if extensive new development is required, Category I through IV tests are indicated. If the system configuration represents a low-risk investment and constitutes mostly off-the-shelf items, then only Category III and IV tests may be necessary. Every system acquisition will require a specific combination of tests and demonstrations involving one or more of the types of tests defined previously.

6-1.2 INTERRELATIONSHIPS

The development testing, maintainability testing, and maintenance evaluation–each in its individual way–contribute to the validation of the total logistic support package.

Various forms or types of test, not strictly related to the maintenance support aspects, are conducted during the materiel development which serve as a source of data for the maintenance engineering process. These tests include breadboard, engineering, subsystem, and component testing. The maintenance engineer may use the results of these tests or may conduct analysis on the materiel available (mock-ups, engineering models, prototypes) to insure that the maintenance engineering analysis package being prepared reflects the materiel demands related to maintenance resources. These tests, as stated, although not conducted specifically to verify the maintenance package, provide the maintenance engineer with the tool by which to make decisions. From detailed analysis of a nonfunctional mock-up, the maintenance engineer can determine preliminary tool requirements, assembly and disassembly order, access for servicing, etc. As a result, recommendations for correction of deficiencies can be made in the early design stages. Through a coordinated test planning effort, the formal tests designated as Categories 11, 111, and IV (pars. 6-1.1.2 through **6-1.1.4)** may be used to assist the formal validation and evaluation of both the maintainability and maintenance aspects of the developed materiel.

The maintainability demonstration is essentially a formal test. Although its parameters also may be evaluated as a result of other tests, the formal maintainability test provides the data and controlled atmosphere for validation of the quantitative and qualitative maintainability parameters of the system. Since the demonstration is conducted in an environment similar to operational conditions and uses the proposed maintenance resources (tools, test equipment, technical publications, handling equipment), it verifies the maintenance package and performance requirements in addition to maintainability. The demonstration verifies compliance with the corrective and preventive maintenance time requirements. **As** such, it validates the fault isolation requirement and the detailed time for the corrective maintenance action elements (diagnosis, fault isolation, remove/replace, and verify) and the interacting qualitative features (packaging, accessibility, etc.).

The maintenance evaluation is conducted to evaluate the maintenance procedures, the maintenance data package and resulting maintenance materiel resources, and their capability to support the developed materiel as planned.

The evaluation of the maintenance engineering package is not a discrete, independent function, clearly separated from other test or demonstration functions. Maintenance evaluation is an all-encompassing action that capitalizes on the data resulting from all test activity to aid in the maintenance engineering analysis process and to maintain the maintenance engineering analysis data system in a current status to reflect the concept of total logistic support.

6-2 TESTING

Materiel is subjected to numerous tests during its life cycle. The planning for these tests is initiated in the conceptual phase, and the tests start as soon as hardware is available.

6-2.1 TYPES OF TESTS

Basically, the test program is conducted to verify the feasibility, performance characteristics, and/or supportability of the system.

Formal verification of the performance and design usually is demonstrated by completion of specific test/verification functions such as:

a. Engineering test and evaluation, performed primarily to acquire data necessary to support the design and development of the item.

b. Qualification inspection, performed to demonstrate performance and design adequacy. This effort includes:

(1) Inspection (physical characteristics, materials, processes and parts, nameplates and product marking, workmanship, and safety)

(2) Analyses (useful life, preventive and corrective maintenance time, packaging, service and access, maintenance safety, handling, reliability)

(3) Demonstrations (transportability, human performance/human engineering, maintainability, system test)

(4) Tests:

(a) Interface, performed to demonstrate interface compatibility with associated equipment. Verifies all mechanical, electrical, and other interface requirements.

(b) Environmental, performed to verify compliance with environmental requirements (low/high temperature, thermal shock, atmospheric pressure, humidity, sand and dust, salt spray, fungus, etc.).

(5) Electromagnetic interference, performed to demonstrate conformance to RFI requirements.

c. Reliability verification, performed to demonstrate, either by test or analysis, the reliability requirements.

d. Maintainability analysis, performed to evaluate, by analysis, compliance with maintainability requirements.

e. Engineering critical item qualification.

f. Visual examination and performance test, performed to determine compliance with the part, material, construction, and workmanship requirements.

g. System test, performed to verify the performance requirements of the item that cannot be verified until the item is assembled into or used with the system.

The test program, comprised of development and operational tests, is initiated in the validation phase and continues throughout the materiel life cycle (Fig. 6-2).

6-2.1.1 Development Test and Evaluation (DT&E) (Ref. 2)

Development test and evaluation are conducted by AMC to demonstrate that the engineering design and development process is complete, the design risks have been minimized, and the system will meet specifications, and to estimate the system military utility when introduced. The tests should start as early in the development cycle as possible and should include testing of component(s), subsystem(s), and prototype or preproduction model(s) of the entire system. Compatibility and interoperability with existing or planned equipments and systems should be tested.

During the development phase following initiation of the program, adequate development test and evaluation should be accomplished to demonstrate that technical risks have been identified and solutions are available. During the full-scale development and prior to the first major production decision, the tests accomplished shall insure that:

a. Engineering is reasonably complete.

b. All significant design problems (compatibility, interoperability, reliability, maintainability, and logistic considerations) have been identified.

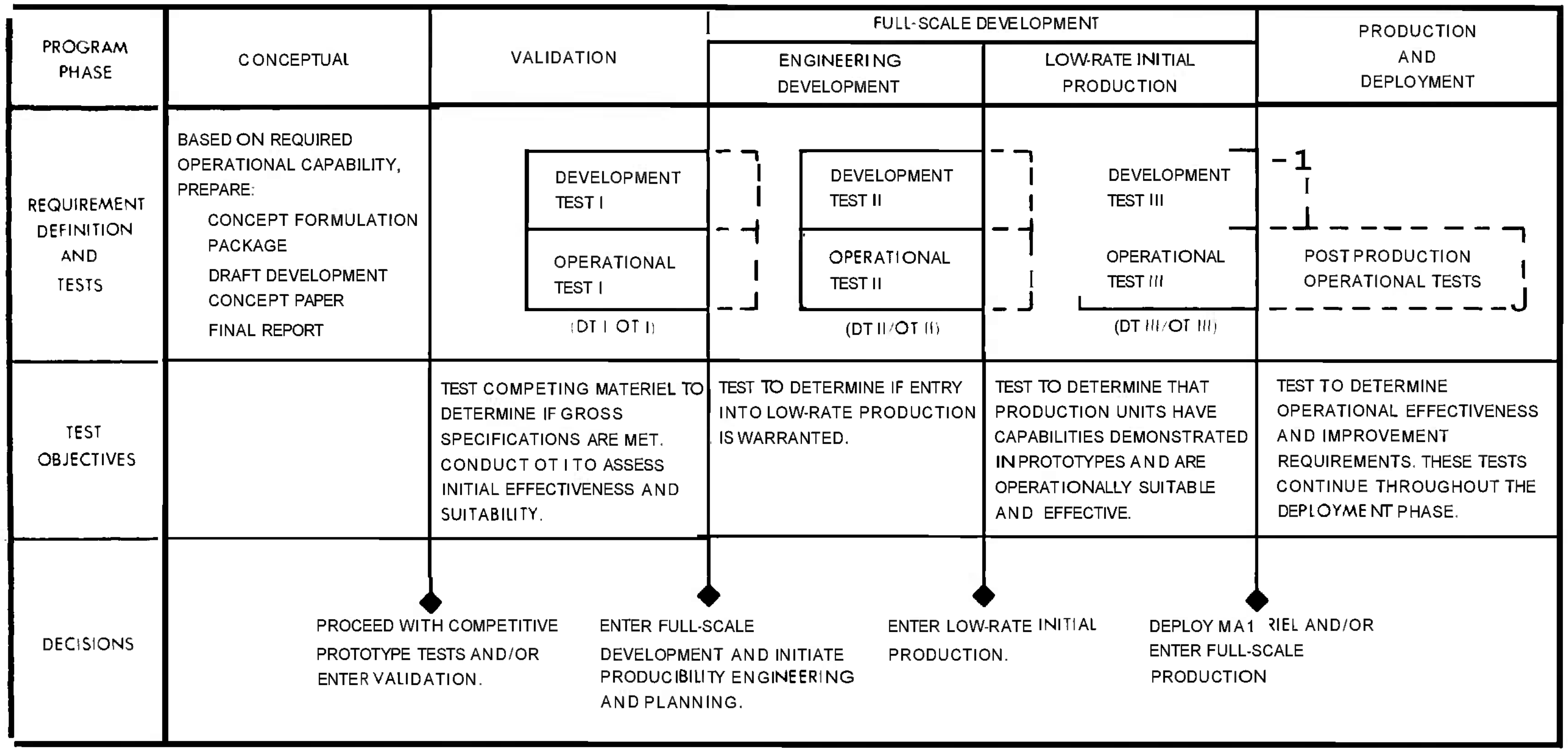
c. Solutions to the problems are available.

The major development tests are (Ref. 3):

a. DT I. Begins early in the development cycle, normally during the validation phase, to demonstrate that technical risks have been identified and solutions are available.

b. DT 11. Provides technical data for determining the system readiness for transition to either low-rate or full-scale production phase. DT II is a two-phased test in which engineering and service-use performance aspects are examined. It measures the technical performance of item and associated support equipment, the developmental training and maintenance packages, human engineering aspects, and performance of training devices and methods.

c. DT 111. Conducted on items/systems from the initial production run to verify that the system meets the contract specifications



PROGRAM PHASE	CONCEPTUAL	VALIDATION	FULL-SCALE DEVELOPMENT		PRODUCTION AND DEPLOYMENT
			ENGINEERING DEVELOPMENT	LOW-RATE INITIAL PRODUCTION	
REQUIREMENT DEFINITION AND TESTS	BASED ON REQUIRED OPERATIONAL CAPABILITY, PREPARE: CONCEPT FORMULATION PACKAGE DRAFT DEVELOPMENT CONCEPT PAPER FINAL REPORT	DEVELOPMENT TEST I OPERATIONAL TEST I (DT I OT I)	DEVELOPMENT TEST II OPERATIONAL TEST II (DT II/OT II)	DEVELOPMENT TEST III OPERATIONAL TEST III (DT III/OT III)	POST PRODUCTION OPERATIONAL TESTS
TEST OBJECTIVES		TEST COMPETING MATERIEL TO DETERMINE IF GROSS SPECIFICATIONS ARE MET. CONDUCT OT I TO ASSESS INITIAL EFFECTIVENESS AND SUITABILITY.	TEST TO DETERMINE IF ENTRY INTO LOW-RATE PRODUCTION IS WARRANTED.	TEST TO DETERMINE THAT PRODUCTION UNITS HAVE CAPABILITIES DEMONSTRATED IN PROTOTYPES AND ARE OPERATIONALLY SUITABLE AND EFFECTIVE.	TEST TO DETERMINE OPERATIONAL EFFECTIVENESS AND IMPROVEMENT REQUIREMENTS. THESE TESTS CONTINUE THROUGHOUT THE DEPLOYMENT PHASE.
DECISIONS	PROCEED WITH COMPETITIVE PROTOTYPE TESTS AND/OR ENTER VALIDATION.	ENTER FULL-SCALE DEVELOPMENT AND INITIATE PRODUCIBILITY ENGINEERING AND PLANNING.	ENTER LOW-RATE INITIAL PRODUCTION.	DEPLOY MATERIEL AND/OR ENTER FULL-SCALE PRODUCTION	

Figure 6-2. Test Program-Program Phase Relationship (Ref. 2)

and the characteristics prescribed in a development plan, and to insure the adequacy and quality of the materiel when manufactured according to production specifications and quantity production processes. DT III includes testing to confirm corrective actions taken as a result of prior test programs.

Engineering design testing is conducted concurrently with the major development tests to:

a. Determine that critical system technical characteristics are achievable.

b. Provide data for refining and ruggedizing hardware configurations and interfaces to achieve required technical system characteristics.

c. Eliminate, to the extent possible, technical and design risks or determine the extent to which they are manageable, and verify adequacy of design changes.

d. Provide information in support of development efforts.

e. Assure that components, subsystems and systems are adequately developed prior to entry into DT and Operational Test (OT).

Planned engineering design tests may be made a part of the coordinated test plan (par. 6-2.7) for information. However, if the purpose of design testing is to resolve critical questions normally addressed in DT I or DT II, the engineering design tests will be included in the coordinated test plan.

6-2.1.2 Operational Test and Evaluation (OT&E) (Ref. 2)

Operational test and evaluation are conducted by the user to estimate the prospective system military utility, operational effectiveness and suitability (including compatibility, interoperability, reliability, maintainability, and logistic and training requirements), and need for any modifications. In addition, OT&E provides information on organization, personnel requirements, doctrine or tactics, and data to support or verify materiel as necessary during and after the production period to refine these estimates, to evaluate changes, and to reevaluate the system to insure that it continues to meet operational needs and retains its effectiveness in a new environment or against a new threat.

The major operational tests are (Ref. 3):

a. OT I. Examines the hardware configuration of a system, or components thereof, to provide an indication of utility and worth to the user. OT I is conducted during the validation phase on advanced development components and system prototypes to provide information leading to the decision to proceed to full-scale development. OT I assesses the potential of the new item/system in relation to existing capabilities, the relative merits of available competing prototypes/systems from the aspect of operational utility, the adequacy of the concepts for employment, integrated logistic support, organization and training requirements, and related operational critical items.

b. OT II. Examines engineering development/preproduction prototype equipment prior to the initial production decision. OT II assesses the military utility of the materiel, operational effectiveness, and operational suitability in as realistic an operational environment as possible.

c. OT III. Examines initial production items. OT III has the fundamental purpose of assuring that the materiel is operationally suitable, that all operationally critical issues have been resolved, and that all benefits and burdens of the materiel are identified.

Operational testing should be separate from development testing. However, development testing and early phases of operational testing may be combined when separation would cause delay involving unacceptable military risk, or would cause an unacceptable increase in the acquisition cost of the system. When combined testing is conducted, the report and evaluation process for DT I and OT I will be separate (Ref. 2).

6-2.2 TEST PROGRAMS (Ref. 4)

Early in the development cycle, consideration must be given to the overall test program that is to be followed in assessing the merit of the item under development. In developing an overall test program, emphasis must be placed on establishing the most practical and beneficial relationship among the test programs. Three types of test programs are applicable:

a. Integrated Test Program. An integrated (development/operational) test program is the goal of all test planning, and should be given first consideration in the early planning of all development programs. An integrated test program is appropriate when tests involve expensive, low-density materiel, when the number of prototypes available is inadequate for concurrent testing, and when the validity of test results is not jeopardized by such a program.

b. Concurrent Test Program. A concurrent (development/operational) test program should be considered when an integrated test program is not advisable. A concurrent test program is appropriate when tests involve high-density materiel and when the number of available prototypes is adequate for such a program.

c. Sequential Test Program. A sequential (development/operational) test program is appropriate when integrated and concurrent test programs are not practical, when the number of prototypes available is inadequate for concurrent testing, or when a requirement exists for separate, unusual test conditions and facilities.

6-2.3 EARLY IDENTIFICATION OF TEST METHOD (Ref. 4)

A document that portrays the overall test program is a coordinated test plan. The coordinated test plan forecasts test requirements as far in advance as possible and will be reviewed for adequacy at in-process reviews. Its objectives are to insure maximum efficiency in the use of material, and rapid and complete distribution of test information. The need for early identification of the test methods and of the test program is necessary to insure:

a. That interested agencies will derive maximum benefit from each test.

b. That each test embodies the best available techniques and scientific methodology.

c. That evaluation is based on methods which produce factual data and eliminate any element of personal bias.

d. The greatest possible integration of the testing effort to avoid duplication of tests, test facilities, equipment, and personnel.

The test plan is the basic document that defines all assigned tests to be performed on materiel, items, or systems. The plan is prepared to assure that materiel is properly and significantly tested, and to reduce testing lead time and costs.

6-2.4 TEST PLAN CRITERIA (Ref. 3)

The criteria used in the development of test plans are, in addition to those for early selection of the test method, as follows:

a. Limit the testing activities to actions necessary to determine compliance with requirements in the required operational capability documents.

b. Provide a concise statement of approach, test criteria, test objectives, and the scope and length of tests.

c. Identify the subtests necessary to determine the degree to which an item meets or exceeds the required operational capabilities documents.

d. Plan and coordinate the test program at the earliest possible time.

e. Integrate test planning for environmental testing when suitable climate and terrain conditions are available only for short test seasons.

f. Make maximum use of existing facilities in lieu of new construction and procurement.

g. Plan for utilization of modern mathematical and statistical methods and, when cost-effective, automated systems.

h. Provide for adequate safety precautions, based on safety experience on similar test programs.

i. Insure the availability of test support materiel.

6-2.5 TEST SUPPORT PLANNING (Ref. 4)

Planning for test support must be an integral part of test planning and must be included in the early stages of funding and development of coordinated test plans. Necessary logistic support, including repair parts, must be available throughout the testing cycle in order to avoid delay due to failures in materiel under test or in ancillary test support equipment.

The plan for test support will include:

a. The listing, quantity, and firm availability date of test support and control items

b. Arrangements for transportation of the test items, special tools, special test equipment, repair parts, technical literature, and other test support items to the test site at the specified time

c. Emergency transportation to avoid possible delays during critical test periods

d. Availability of competent personnel support, including contractor assistance when needed

e. Availability of testing facilities

f. Assignment of responsibilities, including funding responsibilities

g. For guided missiles, a statement from the appropriate national range commander indicating his coordination and estimate for additional facilities and instrumentation required by the range to support the plan.

6-2.6 FUNDING (Ref. 3)

Funding for conduct of tests is dependent upon the purpose of the test and/or source of the item to be tested. Funds for the development test are programmed and budgeted by the materiel developer. Funds required for conduct of operational test are programmed and budgeted by the operation test and evaluation agency. The costs of conducting the engineering tests and development tests I and II—including the cost of test items, support equipment, training of personnel, and repair parts—are funded from research, development, test, and evaluation (RDT&E) appropriations, except when these items are procured by other funds.

6-2.7 PLANNING

The coordinated test plan is the key management document for assuring that appropriate tests are accomplished and that the activity is properly planned, coordinated, conducted, analyzed, and reported.

The coordinated test plan lists the critical issues to be addressed by testing. Depending on the type of item(s) or systems being developed, the areas of risk in the program may be related to areas of design or support. The tests designated for the test program should insure that the item(s) or system(s) will perform in accordance with the intended use. Detailed testing may be required in specific design areas to verify analytical theoretical concepts in relation to the actual performance. Areas in relation to fault isolation and level of repair would be of prime concern. Once testing verifies the design performance, the other areas of maintainability, reliability, and supportability are assessed in the test program. Areas of consideration in test planning are:

a. Adequate testing in the areas of high risk related to design

b. Proper scheduling for availability of resources to conduct the test as planned. Resources include equipment, test procedures, personnel, time, funding, and support test equipment

c. Contingency plans in case of delays in availability of resources

d. Commitments to other facilities for usage in test program and conformance to local restrictions or regulations, if applicable

e. Assurance that new test, measurement, and diagnostic equipment, when essential, will be conceived, defined, developed, tested, produced, procured, and issued concurrently with the end item(s) or system(s) supported

f. Variability or uniqueness of the test method proposed for verification of the performance

g. Calibration cycles and time for item(s)/system(s) or test support items

h. Supportability in test program, based on fault isolation capability or hardware level.

6-2.8 TEST DATA IN THE MAINTENANCE ENGINEERING ANALYSIS PROCESS

The results of the test program development and operational tests are used in the overall maintenance engineering analysis process. Information generated in relation to support resources, (repair parts, publications, training, tools and test equipment, maintenance support, etc.) is used as the basis for development of the test support materiel. Based on the requirements identified, the materiel is developed, procured, or produced to be available for use in the testing, maintainability demonstration, and/or maintenance evaluation. Likewise, performance test data are used to update or refine the maintenance engineering analysis data system and to initiate changes in the support resources, as required. The test program may reveal inadequacies in the technical manuals related to operation or maintenance, and deficiencies in the level of fault isolation, requiring more spares support, specialized training, or higher skill levels. The test programs verify the analytical, statistical, or paper analysis efforts in the operational environment. Any changes or deviations from the initial maintenance engineering analysis and the test results should be resolved. In addition to providing a firm foundation for update of the data system, the test data also provide a basis for evaluation of the maintenance engineering analysis process. The updated data developed for the materiel may be used to assist in the maintenance engineering analysis process on comparative equipment. This data bank source of information complements the overall analysis process.

Specific data obtained from the test program and used in the maintenance engineering analysis process consist of, but are not limited to, the following:

a. Operating life characteristics—Identify any wearout tendency that could be offset by scheduled preventive maintenance or overhaul.

b. Reliability characteristics—Describe reliability of the item in terms of failure rates or mean time between failures.

c. Task analysis characteristics—Update the task analysis flow information and sequences as a result of procedural fault isolation and corrective maintenance sequence.

(1) Teardown sequence—Provide the detail in relation to the remove/replace of item(s)/equipment(s) or system(s).

(2) Support resources—Provide the verification of the adequacy of publications, tools, and skill levels, or the basis for changes to these resources.

(3) Time-to-repair characteristics—Identify the elemental times related to the time to repair in relation to fault isolation, remove, replace, repair, and verify.

(4) Provisioning and repair parts—Provide the data required to finalize the maintenance factor (i.e., failures/100 items/year) to be used in the repair part selection process.

(5) Operational characteristics—Provide the data to determine the operational verification after repair and calibration requirements.

d. Support and planning characteristics—Provide verification of these characteristics or the basis for changes in hardware design, support equipment design, or initiation of logistic support trade-offs in relation to proposed methods of repair and replacement for each level of maintenance, skill levels for each level, materiel handling requirements, provisions for scheduled and unscheduled maintenance, and climatic and environmental allowances.

6-2.9 TEST, MEASUREMENT, AND DIAGNOSTIC EQUIPMENT (Ref. 5)

The following criteria should be considered in the selection of test, measurement, and diagnostic equipment for either special tests or for deployment.

a. Optimize effectiveness and utility.

b. Optimize simplicity of design, maintainability, and reliability.

c. Eliminate unnecessary preparation and duplication.

d. Insure that the type and quantity selected for inventory are justified by need and cost effectiveness.

e. Use available TMDE that is in the Army inventory to the greatest extent possible. Procurement requests for TMDE shall not be processed until the item has been approved by the central DA TMDE Activity (Ref. 10).

f. Insure that test, measurement, and diagnostic equipment, when essential, is conceived, defined, developed, tested, produced, procured, and issued concurrently with the end item or system supported.

g. Acquire and maintain test, measurement, and diagnostic equipment consistent with the modular design/maintenance concept.

6-2.10 SAMPLING, ACCURACY, AND CONFIDENCE LEVEL (Ref. 6)

In the test phase, in order to verify certain performance parameters of the system, information is obtained and decisions are made based on sampling. Sampling techniques are necessary or desirable when constraints of cost and time are prohibitive, precise information regarding total population is not necessary, or the test is destructive in nature. Qualification and design verification tests fall in the category of attitude tests. These are usually goho-go tests used to demonstrate that a device is good or bad without showing how good or how bad. Maintainability tests and maintenance evaluation tests, however, are conducted to determine the degree of compliance with the performance requirements and also to determine, in terms of time or the precise conditions required, the variance from the maintenance resource documentation.

To avoid bias in the sampling, the total sample N is selected at random from the total population in which every item has a known probability of being selected. From the total samples N, task samples n are selected from a category, group, or class of item(s), materiel, etc., based on the relative frequency of failure.

The measure of central tendency and the dispersion of data are the mean and the standard deviation, respectively. The arithmetic mean of the population and the arithmetic mean of the sample are represented by:

$$\mu = \frac{\Sigma X}{N} \tag{6-1}$$

$$\overline{X} = \frac{\Sigma X}{n} \tag{6-2}$$

where

μ = population mean

$\overline{X}$ = sample mean

N = total population

n = sample population

X = value of each observation in the population or sample size

The standard deviation is a measure of dispersion of the population about the mean, or a measure of availability. The standard deviation of the population and the standard deviation of the sample are represented by:

$$\sigma = \sqrt{\frac{\Sigma(X-\mu)^2}{N}} \tag{6-3}$$

$$s = \sqrt{\frac{\Sigma(X-\overline{X})^2}{n-1}} \tag{6-4}$$

where

σ = standard deviation of the population of size N

s = standard deviation of the samples of size n

The standard deviation of the distribution of the sample means $\sigma_{\overline{X}}$ (standard error of the means) is equal to

$$\sigma_{\overline{X}} = \frac{\sigma}{\sqrt{n}} \tag{6-5}$$

Since s is an unbiased estimate of σ,

$$\sigma_{\overline{X}} \approx \frac{s}{\sqrt{n}} \tag{6-6}$$

In the case of verification of a maintenance or maintainability parameter, the basic approach is to perform maintenance analysis and evaluation on a randomly selected sample of items from the total population of items that comprise the system (Ref. 6).

The basic question in testing the maintainability parameters is: How many cases n must be evaluated out of a given population distribution to assure a given confidence level ϕ that the sample mean will be within a given accuracy k?

Stated more directly, what must the sample size n be to insure **a** 95 percent probability ϕ that the arithmetic mean of the sample will be within a 10 percent accuracy k of the true mean of the population from which the sample was taken?

The following points of statistical theory are pertinent:

a. Regardless of the shape of the underlying population distribution, the mean of several sample means always will be normally distributed, and the mean of the sample means will be the same as the population mean. This relationship is shown in Fig. **6-3.** For example, if a sample of 10 cases from a given population were taken, the arithmetic mean could be computed. This sample mean is one estimate of the population mean. Additional samples would show that these are distributed normally about a central value, which is the mean of the sample means.

b. Regardless of the shape of the underlying population distribution, the standard deviation $\sigma_{\overline{X}}$ of the normally distributed sample means is affected by the standard deviation σ of the population distribution and the square root of the number of cases n in the sample size according to Eq. 6-5 repeated here.

$$\sigma_{\overline{X}} = \frac{\sigma}{\sqrt{n}}$$

c. Regardless of the shape of the underlying population distribution, the normal distribution of the sample means may be compressed by increasing the number of cases n in each sample. In simple terms, the sample means can be forced closer to the population mean by increasing the sample size. When the number of cases n in the sample equals the number of cases in the population N, the standard deviation of the sample means is zero; therefore, the mean of the sample is equal to the mean of the population.

Restating the basic question in terms of the normal distribution of sample means would yield: What sample size n is required to assure a probability of 0.95 that a particular sample mean is within 10 percent of the mean of the normally distributed sample means?

The basic equation for determining the confidence level ϕ corresponding to the probability in question is as follows:

$$\phi = \frac{k\overline{X}}{\sigma_{\overline{X}}} \tag{6-7}$$

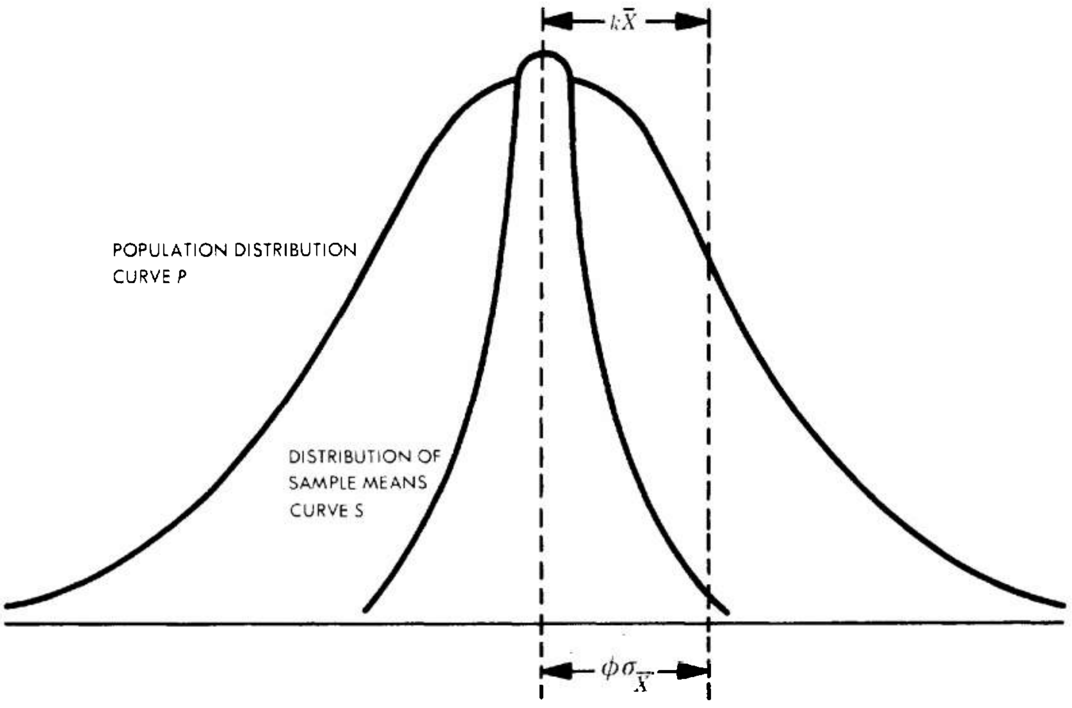


Figure 6-3. Comparison of Population and Sampling Mean Distribution

where

k = accuracy of the prediction given as a percent of the mean

$\overline{X}$ = population mean of sample

$\sigma_{\overline{X}}$ = standard deviation of the distribution of the sample means

ϕ = confidence to be applied to the measurement (This value is obtained from the table of cumulative distribution (Table 6-1) and is 1.645 for 95 percent confidence.)

Eq. 6-7 can be restated in terms of population distribution by substituting Eq. 6-5 for $\sigma_{\overline{X}}$, which yields:

$$\phi = \frac{k\overline{X}\sqrt{n}}{\sigma} \tag{6-8}$$

Eq. 6-8 then represents the normal distribution of the sample means stated in terms of the population distribution parameters ($\overline{X}$ and (T), assuming that $\overline{X}$ is the best estimate of μ.

The expression for sample size is derived by multiplying both sides of Eq. 6-8 by $\sigma/(k\overline{X})$ and squaring both sides of the equation which yields:

$$n = \left(\frac{\phi\sigma}{k\overline{X}}\right)^2 \tag{6-9}$$

Eq. 6-9 may be used to determine the number of samples n required to assure a confidence level @ that the sample mean $\overline{X}$ will have an accuracy k; i.e., within the range of $\overline{X} + k\overline{X}$ when the population mean is $\overline{X}$ and the standard deviation is (T.

The term $\sigma/\overline{X}$ may be labeled the coefficient of variation designated as C_X; thus Eq. 6-9 becomes:

$$n = \left(C_X \frac{\phi}{k}\right)^2 \tag{6-10}$$

In most cases the standard deviation σ of the population is not known but must be approximated. Thus the value of C_X must be approximated to establish the magnitude of sample size n based on Eq. 6-10. This estimate of C_X should be based on experience with similar systems from which adequate measures are available. Field experience with ground electronic equipment has shown that, when applied to this procedure, a practical estimate for C_X is 1.07 (Ref. 6).

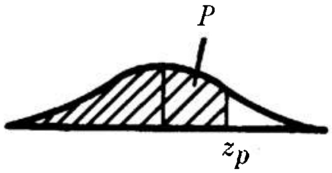
6-3 MAINTAINABILITY DEMONSTRATION

A maintainability demonstration is an effort to demonstrate the achievement of contractual maintainability requirements in a simulated operational environment. The conduct of the demonstration is normally governed by MIL-STD-471A (Ref. 8). However, the Army may modify the provisions of this standard when it is considered to be cost-effective. All demonstrations are conducted in accordance with a detailed plan.

Normally, the maintainability demonstration is conducted with prototype hardware. Therefore, the time frame of its conduct will approximate the time at which limited production is initiated. The demonstration is preceded by a verification effort and followed by an evaluation. Verification is accomplished, commencing with initial design and continuing through development. The basic purposes of verification are to verify predicted maintainability data by using development test data, and to detect and correct design deficiencies early in the development program. Maintainability evaluation is conducted after the materiel is deployed. Its basic purpose is to evaluate the impact of the actual operational, maintenance, and support environment on materiel maintainability.

A maintainability demonstration is not to be confused with maintenance evaluation (par. 6-5), although tactical-type support equipment, tools and test equipment, technical data, repair parts, calibration equipment, etc., are used in both activities. The maintainability demonstration is conducted in a simulated operational environment, and faults are inserted to be detected while the materiel is operating. The basic purpose of the demonstration is to determine if the fault can be isolated and repairs effected with specified resources in a specified time. The maintenance evaluation involves the

TABLE 6-1. CUMULATIVE NORMAL DISTRIBUTION—VALUES OF *P* (Ref. 7)



Values of P corresponding to z_p for the normal curve.
z is the standard normal variable. The value of P for $-z_p$ equals 1 minus the value of P for $+z_p$, e.g., the P for -1.62 equals $1 - 0.9474 = 0.0526$.

z_p	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
0.0	0.5000	0.5040	0.5080	0.5120	0.5160	0.5199	0.5239	0.5279	0.5319	0.5359
0.1	0.5398	0.5438	0.5478	0.5517	0.5557	0.5596	0.5636	0.5675	0.5714	0.5753
0.2	0.5793	0.5832	0.5871	0.5910	0.5948	0.5987	0.6026	0.6064	0.6103	0.6141
0.3	0.6179	0.6217	0.6255	0.6293	0.6331	0.6368	0.6406	0.6443	0.6480	0.6517
0.4	0.6554	0.6591	0.6628	0.6664	0.6700	0.6736	0.6772	0.6808	0.6844	0.6879
0.5	0.6915	0.6950	0.6985	0.7019	0.7054	0.7088	0.7123	0.7157	0.7190	0.7224
0.6	0.7257	0.7291	0.7324	0.7357	0.7389	0.7422	0.7454	0.7486	0.7517	0.7549
0.7	0.7580	0.7611	0.7642	0.7673	0.7704	0.7734	0.7764	0.7794	0.7823	0.7852
0.8	0.7881	0.7910	0.7939	0.7967	0.7995	0.8023	0.8051	0.8078	0.8106	0.8133
0.9	0.8159	0.8186	0.8212	0.8238	0.8264	0.8289	0.8315	0.8340	0.8365	0.8389
1.0	0.8413	0.8438	0.8461	0.8485	0.8508	0.8531	0.8554	0.8577	0.8599	0.8621
1.1	0.8643	0.8665	0.8686	0.8708	0.8729	0.8749	0.8770	0.8790	0.8810	0.8830
1.2	0.8849	0.8869	0.8888	0.8907	0.8925	0.8944	0.8962	0.8980	0.8997	0.9015
1.3	0.9032	0.9049	0.9066	0.9082	0.9099	0.9115	0.9131	0.9147	0.9162	0.9177
1.4	0.9192	0.9207	0.9222	0.9236	0.9251	0.9265	0.9279	0.9292	0.9306	0.9319
1.5	0.9332	0.9345	0.9357	0.9370	0.9382	0.9394	0.9406	0.9418	0.9429	0.9441
1.6	0.9452	0.9463	0.9474	0.9484	0.9495	0.9505	0.9515	0.9525	0.9535	0.9545
1.7	0.9554	0.9564	0.9573	0.9582	0.9591	0.9599	0.9608	0.9616	0.9625	0.9633
1.8	0.9641	0.9649	0.9656	0.9664	0.9671	0.9678	0.9686	0.9693	0.9699	0.9706
1.9	0.9713	0.9719	0.9726	0.9732	0.9738	0.9744	0.9750	0.9756	0.9761	0.9767
2.0	0.9772	0.9778	0.9783	0.9788	0.9793	0.9798	0.9803	0.9808	0.9812	0.9817
2.1	0.9821	0.9826	0.9830	0.9834	0.9838	0.9842	0.9846	0.9850	0.9854	0.9857
2.2	0.9861	0.9864	0.9868	0.9871	0.9875	0.9878	0.9881	0.9884	0.9887	0.9890
2.3	0.9893	0.9896	0.9898	0.9901	0.9904	0.9906	0.9909	0.9911	0.9913	0.9916
2.4	0.9918	0.9920	0.9922	0.9925	0.9927	0.9929	0.9931	0.9932	0.9934	0.9936
2.5	0.9938	0.9940	0.9941	0.9943	0.9945	0.9946	0.9948	0.9949	0.9951	0.9952
2.6	0.9953	0.9955	0.9956	0.9957	0.9959	0.9960	0.9961	0.9962	0.9963	0.9964
2.7	0.9965	0.9966	0.9967	0.9968	0.9969	0.9970	0.9971	0.9972	0.9973	0.9974
2.8	0.9974	0.9975	0.9976	0.9977	0.9977	0.9978	0.9979	0.9979	0.9980	0.9981
2.9	0.9981	0.9982	0.9982	0.9983	0.9984	0.9984	0.9985	0.9985	0.9986	0.9986
3.0	0.9987	0.9987	0.9987	0.9988	0.9988	0.9989	0.9989	0.9989	0.9990	0.9990
3.1	0.9990	0.9991	0.9991	0.9992	0.9992	0.9992	0.9992	0.9992	0.9993	0.9993
3.2	0.9993	0.9993	0.9994	0.9994	0.9994	0.9994	0.9994	0.9995	0.9995	0.9995
3.3	0.9995	0.9995	0.9995	0.9996	0.9996	0.9996	0.9996	0.9996	0.9996	0.9997
3.4	0.9997	0.9997	0.9997	0.9997	0.9997	0.9997	0.9997	0.9997	0.9997	0.9998

determination of maintenance levels and specific support resource requirements, performance of maintainability analyses, and disassembly and assembly of materiel, but does not involve fault 'detection and isolation.

6-3.1 GENERAL REQUIREMENTS

The requirements that follow apply to all maintainability demonstrations. Additional requirements or changes may be imposed on individual procurements.

a. The maintainability demonstration shall be conducted in an environment that simulates, as closely as practicable, the operational and maintenance environment planned for the item. This environment shall be representative of the working conditions, tools, support equipment, spares, facilities, and technical publications that would be required during operational service use at the maintenance level defined in the approved maintenance plan.

b. In conjunction with the maintainability demonstration, the approved integrated support plan, when required, scaled to the number of test items used in the demonstration, shall be implemented by the test team to identify the logistic support provided.

c. All maintenance data, including depot level, shall be recorded and reported to the test team as specified by the procuring activity.

d. Unless otherwise approved by the procuring activity, the configuration of the items of the system selected for demonstration shall be documented and certified by a physical configuration audit.

e. Unless otherwise approved by the procuring activity, all support equipment used during the demonstration shall be certified by a physical configuration audit.

f. Maintenance tasks that may require fault simulation shall require that the item be checked for normal operation prior to failure simulation and after completion of the specified maintenance task. When a failure is simulated, it will be the responsibility of the test team to select the maintenance task, the failure to be simulated, and the failure mode, and to verify 'that the degree of failure is representative of the maintenance task to be demonstrated. The work area in which degradation or failure of parts has been simulated shall contain no obvious evidence other than that normally resulting from the simulated mode of failure. The appearance of a defective part that is substituted for a serviceable part shall be that of a normally failed part. The technician shall not witness any fault insertion. Simulation of failures by introduction of faulty parts will not be used when the normal procedures could result in extensive damage to the equipment or item being tested. Each defective part is to be installed in the equipment in the same manner as the original part.

g. For maintenance tasks whose faults have been simulated, the presence of necessary repair parts, tools, test and support equipment, or technical publications shall not assist in fault isolation by prematurely identifying the work to be done. Such items shall be covered or otherwise kept out of sight from the technician. However, simulated discrepancy data shall be made available, if applicable.

h. Technicians shall have received the training and be of the equivalent skill level as specified in the standard personnel resource documentation for the specified level of maintenance.

i. Each maintenance task will be documented by personnel designated by the test team. The total time measured for a technician to perform each maintenance task shall be recorded and will include the time to perform each element of maintenance time shown in Fig. **4-2.** Each element will be documented separately. The total delay time for each maintenance task shall be documented. The test plan and procedures shall include delay time rules.

j. The time required to obtain support items (appropriate test and support equipment, tools, repair parts, technical publications, etc.) from the defined work center area shall be recorded. This time shall not, however, be chargeable as maintenance task time for the item being demonstrated unless this time is controlled or influenced by the design of the item being demonstrated.

6-3.2 DEMONSTRATION TEST PLAN

The procuring agency will determine the need for a formal maintainability demonstration. The decision will be based on tactical considerations, mission requirements, cost of tests, and the type of equipment being developed. In some cases, the type of equipment (site, complexity, etc.) would negate the requirement for it demonstration test. In other cases, additional emphasis is stressed by including incentives in the contract.

When a maintainability demonstration is required, the developer is responsible for determining operational constraints, tactical constraints, and/or trade-off analyses that provide a basis for defining the test procedures. As a minimum, this information must include the maintenance concept, a description of the post-deployment maintenance environment, the configuration of the equipment to be tested, the modes of operation for the test, and the levels of maintenance to be demonstrated.

The developer is responsible for preparing a maintainability demonstration plan in accordance with MIL-STD-471A (Ref. 8). Preparation should start at the beginning of the development program. Before the demonstration is conducted, the total plan must receive final approval.

The objective of the maintainability demonstration plan is to prove the compliance of materiel with requirements. The planner must be able to locate the documents that establish requirements, recognize the statements of qualitative and quantitative maintainability requirements, and then translate these requirements into a maintainability demonstration test objective.

The maintainability demonstration test plan is the document governing which maintainability requirements will be demonstrated. Quantitative requirements are stated as time indices, while qualitative requirements are stated in terms of materiel design guidelines. The plan must include, at a minimum, the following sections:

a. Background information

b. Item interfaces

c. Test team

d. Support material

e. Preparation stage

f. Demonstration

g. Retest.

6-3.2.1 Background Information

This section of the demonstration test plan describes the conditions under which the demonstration tests will be performed. It identifies the equipment and the indices, and gives the maintenance concept, the levels of maintenance, and the modes of operation that are to be demonstrated. It gives the specific test objectives and furnishes the information required to convert the test site and facilities to an environment that simulates the one in which tactical maintenance will be performed. It identifies the agencies who will participate in the demonstration and lists the data required from the test. This section of the plan furnishes the link between the demonstration plan and other pertinent documents that have impacted it (i.e., maintenance concept, operational concept, etc.).

Specific subjects covered in this section are:

a. Quantitative and qualitative maintainability requirements

b. Maintenance concept

c. Maintenance environment

d. Level(s) of maintenance

e. Sites

f. Facility requirements

g. Participating agencies

h. Mode(s) of operation of the items, including configuration and mission requirements

i. Items subject to verification, demonstration, and evaluation

j. Data required for completion of the verification/demonstration/evaluation.

6-3.2.2 Item Interfaces

This section of the demonstration test plan forces the planner to evaluate formally the plan in the light of the tactical planning and to identify any special test requirements and/or conflicts with the tactical plan. The adequacy of maintenance planning and the following support resources are discussed:

a. Support and test equipment

b. Supply support

c. Transportation, handling, and storage *d.* Technical data

e. Facilities

f. Personnel and training.

6-3.2.3 Test Team

This section of the demonstration test plan describes the makeup of the test team, gives its organization, describes the qualifications, quantity, sources, training, and indoctrination requirements for the test team personnel, and lists the responsibilities of the team. Each team member is empowered to make decisions for his organization.

Each team member may have advisers from his organization who are knowledgeable in the various aspects of maintainability demonstration. The advisers and their organizations and areas also shall be listed in the plan.

The team shall be organized into two major sections: (1) the demonstration review section, which is responsbile for the conduct of the test and for observation and interpretation of test results, and (2) the maintenance section, which is responsible for the actual performance of the required maintenance actions.

One member of the test team shall be designated in the plan as the test director. He shall coordinate all activity and serve as arbitrator for points of contention during the demonstration.

6-3.2.4 Support Material

This section of the demonstration test plan identifies the support resources that will be used during the demonstration. The following items are included, as applicable:

a. Support equipment

b. Tools and test equipment

c. Technical manuals

d. Repair parts and consumables

e. Safety equipment

f. Calibration equipment.

6-3.2.5 Preparation Stage

This section of the demonstration test plan essentially describes how and when the resources will be acquired with which to conduct the demonstration. Plans are included for training personnel and assembling the test team, preparing the test facilities, and for assembling, checking out, and making a preliminary validation of the support material listed in par. **6-3.2.4.**

6-3.2.6 Demonstration

This section of the demonstration test plan shall include a clear statement of the test objectives, a schedule of the tests, a description of the task selection method, the test method, the data acquisition method, analytical methods, calculation methods, a list of data elements to be collected, the times to be measured, a description of the maintenance tasks, and a schedule showing the types of reports required and the dates on which they are due.

The quantitative requirements will be demonstrated at the system level, unless otherwise stated in the contract. The qualitative requirements that require demonstration will be demonstrated at the end item level.

Current Military Standards contain approved test methods, and are revised periodically. Methods exist to test for mean values, critical percentile values, critical maintenance times, etc. The planner must select methods tailored to meet the requirements at hand. The standards also establish sample sizes and provide computational methods. Task selection is discussed in par. **6-3.3.**

6-3.2.7 Retest

This section of the demonstration test plan contains a provisional schedule for special or repeat tests to investigate deficiencies or trouble areas. Deficiencies shall be corrected in any item that has failed to meet the acceptance criteria. The corrected portions of the item and any other portions of the item affected by the correction shall be retested. The maintenance tasks to be demonstrated shall be as designated by the procuring activity.

6-3.3 TASK SELECTION

The objective of task selection is to select, from the total population of maintenance tasks, a limited number of tasks statistically representative of the total population. Some selection considerations are type of materiel, random versus stratified sampling, task occurrence frequency, and sample size.

6-3.3.1 Type of Materiel

Examples of equipment categories for which various commodity commands have development responsibility range from automotive to aircraft to complex electronic weapon systems. In relation to demonstration, it is advisable to break these classes of systems down into subsystem categories such as electronics, electrical, mechanical, and hydraulic. Each of these categories offers a choice of the maintenance task element that is predominant in terms of time and other logistic resource consumption.

For mechanical or hydraulic subsystems, the predominant maintenance task is the remove/replace operation, whereas in electronic or electrical systems, the predominant maintenance task is diagnostics (malfunction isolation).

The basis for these observations is:

a. Diagnostics of mechanical or hydraulic systems are usually very quick and simple because the human senses (sight, smell, feel, and hearing) are the only requirements imposed by the level of malfunction isolation required for a large percentage of failures. Furthermore, most of these systems are not functionally complex, and any requirements for simple diagnostic aid transducers or troubleshooting logic diagrams are obvious. On the other hand, compared to electronic systems, mechanical systems offer a limited freedom of choice in the way in which they can be packaged, which contributes to the basic problem of long access times and the heavy attendant burden on other logistic resources.

b. There is a tendency toward doing more operations, more accurately and faster with electronics today. This makes these systems very complex functionally, but still leaves an open choice on how the basic elements are packaged and interconnected. Even if diagnostics are performed automatically as part of the basic design, the problem arises as to how effective this design is in terms of the callout size and the percentage of failures for which it works. If diagnostics are performed manually, the problem arises as to how effective the procedures and personnel are and the attendant long diagnostic time.

6-3.3.2 Random Versus Stratified Samples

The basic choice is between simple random sampling and stratified sampling. A simple random sample is one in which all possible tasks in the hypothetical population have an equal chance of being chosen. A stratified random sample is one in which the hypothetical population is divided into subpopulations, sample sizes for each subpopulation are determined from selected criteria, and random sampling is performed within each subpopulation.

Historically, proportional stratified sampling has been used in maintainability. In this method, the sample size from each stratum (e.g., maintenance task group) is proportional to the population size of the stratum. Thus, if there were five strata with relative population sizes of 5, 20, 20, 25, 30, and a total sample of 50 observations were to be made, two or three observations would be selected from the first, or smallest, stratum, 10 from the second and third, 12 or 13 from the fourth, and 15 from the largest stratum.

Table 6-2 compares stratified and simple random sampling. Stratified sampling yields more efficient tests than simple random sampling, provided the following conditions are satisfied:

a. There is a good basis for stratification.

b. The variance within each stratum is small.

c. The population sizes of the strata are known.

d. Appropriate analytical procedures are available.

The first task in stratification is choosing criteria by which to stratify. This involves the characteristic by which to stratify, the number of strata, and the boundaries defining the individual strata. There should be similarities among tasks within a stratum, and the tasks should require approximately the same amount of maintenance time or the same number of man-hours, whichever is appropriate. Repairing a particular electronic assembly may take approximately the same amount of time as repairing a motor generator, but the differences between the two types of actions would make it unnatural to place them in the same stratum.

TABLE 6-2. COMPARISON OF STRATIFIED AND SIMPLE RANDOM SAMPLING

Factor	Comparison
Planning of sample	Stratified sampling requires more detailed planning and knowledge of underlying maintenance task population than does simple random sampling.
Administration of sampling procedure	Stratified sampling includes all administrative aspects of simple random samples plus additional control to meet specification sample size criteria.
Analysis of data	Standard analytical methods are based on simple random sampling. Stratified analytical procedures for stratified samples are relatively complex and may not be available.
Sampling efficiency	Stratified sampling generally is more efficient than simple random sampling, in that variances of sample estimates are lower than for simple random samples.
Subhypotheses	Stratified sampling provides a means to test hypotheses on different portions of the system with adequate control. Such control generally is not available for simple random sampling.
Representativeness	Stratified sampling provides assurance that sample observations from each stratum will be observed. Simple random samples can only provide such assurance probabilistically.

6-3.3.3 Task Occurrence Frequency

Once the initial set of strata has been established, the frequency of occurrence of the tasks in each stratum must be estimated. It is important that realistic failure rates be used. Preferably, these rates should be maintenance factors that truly reflect failures that will be experienced after the materiel is deployed. After the failure rates are established, the relative frequency of task occurrence is calculated as shown in Table **6-3.**

6-3.3.4 Number of Tasks

The number of tasks to be demonstrated is established by the test method used. The number is identified in the test plan. Some of the methods require calculation of sample size. When computations are required, they are a function of the following variables:

a. The difference in the specified and maximum tolerable maintenance index values

b. The consumer's risk

c. The producer's risk

d. The statistical variance of the logarithms of the maintenance time or the maintenance times themselves.

It is desirable to have a large population from which the test sample can be selected, and a ratio of population to test sample of at least 10:1.

An approved listing of the strata and the number of tasks from each that must be included in the test sample are included in the maintainability test plan.

The test plan also includes a list of the actions to be taken in disabling the materiel. These actions are selected to cause predetermined indications that will require representative maintenance actions.

The specific tasks that make up the test sample are selected by a random selection to avoid any prejudicial influence. Unless otherwise specified, preventive maintenance tasks and qualitative maintainability characteristics are demonstrated 100 percent, and sampling usually does not apply. If, however, due to costs or other considerations, sampling for these is

TABLE 6-3. MAINTENANCE TASK POPULATION

Maintenance Task Group	Expected Number of Occurrences in T Hours	Relative Maintenance Task Population
1	E_1	$E_1/E = p_1$
2	E_2	$E_2/E = p_2$
•	•	•
•	•	•
•	•	•
i	E_i	$E_i/E = p_i$
•	•	•
•	•	•
•	•	•
s	E_s	$E_s/E = p_s$
	$E = \sum_{i=1}^{s} E_i$	$\sum_{i=1}^{s} p_i = 1.0$

required, guidelines similar to those followed in selecting corrective tasks are followed.

A quantitative discussion of sample sizes and confidence levels is contained in par. **6-2.10.**

6-3.4 CONDUCT OF DEMONSTRATION

In its broadest sense, a maintainability demonstration requires the simulation of faults (bug insertion), performing maintenance, collecting data, reducing data, and reporting.

6-3.4.1 Bug Insertion

The method of bug insertion should not provide the technician with extraneous information that he would not receive normally under actual maintenance conditions. Taping a pin, therefore, would not be an acceptable method if the level of maintenance or method of diagnostics was such that the technician could detect the method of bug insertion during the maintenance action. Additionally, the bugged equipment should pose no safety hazards.

A review of past maintainability demonstrations indicates that the fault inducement methods involve a great number of disconnects, card removals, wire groundings, and the like, to simulate either shorts or opens. These methods are relatively easy to accomplish; however, they must be controlled so that the equipment is not damaged and the induced fault can be corrected easily upon completion of the maintenance observation. Failures resulting from out-of-tolerance or degradation conditions usually cannot be simulated by these simple methods.

There are several possible approaches to inducing noncatastrophic failures:

a. Replacement of a good part, circuit, or assembly with an identical item having an appropriate type failure.

b. Insertion of extra nondetectable parts, such as a bypass resistor, to simulate an out-of-tolerance condition.

c. Deliberate misalignment.

6-3.4.2 Maintenance Task Accomplishment

During the period when the malfunction to be simulated is being identified and the equipment is being bugged, the personnel of the maintenance section should be located remotely.

After the equipment has been returned to normal appearance, the operational personnel apply power and the system is operated until malfunction indication is obtained. The maintenance section personnel are then notified, and these personnel (including a supervisor) proceed to the equipment area. Using the tools, test and support equipment, and technical publications identified in the maintenance plan, these personnel proceed to isolate, correct, and verify the fault.

Care must be taken that the method of bug insertion and the presence of repair parts, tools, equipment, and/or technical publications do not provide premature identification of the failed item.

Maintenance personnel performing maintenance tasks for the demonstration will be as specified in the test plan and they will be selected for comparative skill levels with the recommended maintenance plan.

The number of observers should be a function of the number of personnel actively engaged in performing the maintenance and the number of locations where maintenance is being performed. The number of observers should be limited to avoid biasing the times by either inducing nervousness, which would tend to increase performance time, or inducing motivational over-response, which would tend to decrease performance time of the personnel engaged in performing the maintenance tasks.

6-3.4.3 Data Collection

The purpose of the maintainability demonstration test is to obtain data that can be used to determine the degree to which the materiel complies with the maintainability requirements.

Data must be collected on the demonstration of both qualitative and quantitative maintainability features. The individual data items (elements) to be collected will vary with the stated maintainability requirements, the materiel being demonstrated, and the type of requirement (qualitative or quantitative). The maintainability demonstration test plan for the particular materiel being demonstrated will describe the data elements to be collected. The formats on which the data will be collected should be included in the plan to provide the test team with the formats and the guidelines for collection of the data. The guidelines should include definition and procedures for collecting the data.

Data recorders will be provided task record sheets similar to the one shown in Fig. 6-4. Fig. 6-5 shows a typical flow diagram, starting with preparation of the task record sheet and concluding with the recording of data.

6-3.4.4 Data Reduction and Analysis

Data reduction and analysis constitute the development of the statistics required by the statistical demonstration test procedures, such as mean number of man-hours to complete corrective maintenance or the time associated with the 95th percentile.

The assumptions made for the statistical test design can first be checked and, if there is indication of a disparity, further analysis will be required before a decision can be made to proceed. An alternate nonparametric test can be used, for example, if it is found that a lognormal distribution assumption is a poor one. The means for calculating the test statistics and the application of the decision criteria will have been determined beforehand and, once numerical values are obtained, the decision of accepting or rejecting is fairly straightforward.

For example, if test method 1A in MIL-STD-471A, (Ref. 8) had been selected as the demonstration test method, the demonstrated maintenance times are applied to an accept/reject formula in the Military Standard, and a decision is made. Other materiel maintainability values also may be calculated. The data obtained by this test method are designed to permit the calculation of mean corrective and mean preventive maintenance times. This information can be used to calculate such values as total active maintenance downtime, mean maintenance downtime, and maximum corrective maintenance downtime.

6-3.4.5 Reporting

The final effort of the demonstration activity is the preparation of the maintainability demonstration report by the review team. For extended test periods, interim reports also may have been prepared.

TASK NUMBER

1. TASK CATEGORY:

   (a) PC Card ( )
   (b) Module ( )
   (c) Power Supply ( )
   (d) Blower ( )
   (e) Miscellaneous ( )

2. TASK DESCRIPTION:

3. FAILURE MODE (SIMULATED):

4. OBSERVED TASK TIME (MINUTES):

   (a) Isolation
   (b) Repair
   (c) Checkout
   Subtotal
   (d) Other
   Total

5. NOTES:

6. WITNESS/DATE:

We certify the above information to be true and correct to the best of our knowledge.

Test Conductor ______________________________ Date ______

Government Representative ______________________ Date ______

Figure 6-4. Task Record Sheet

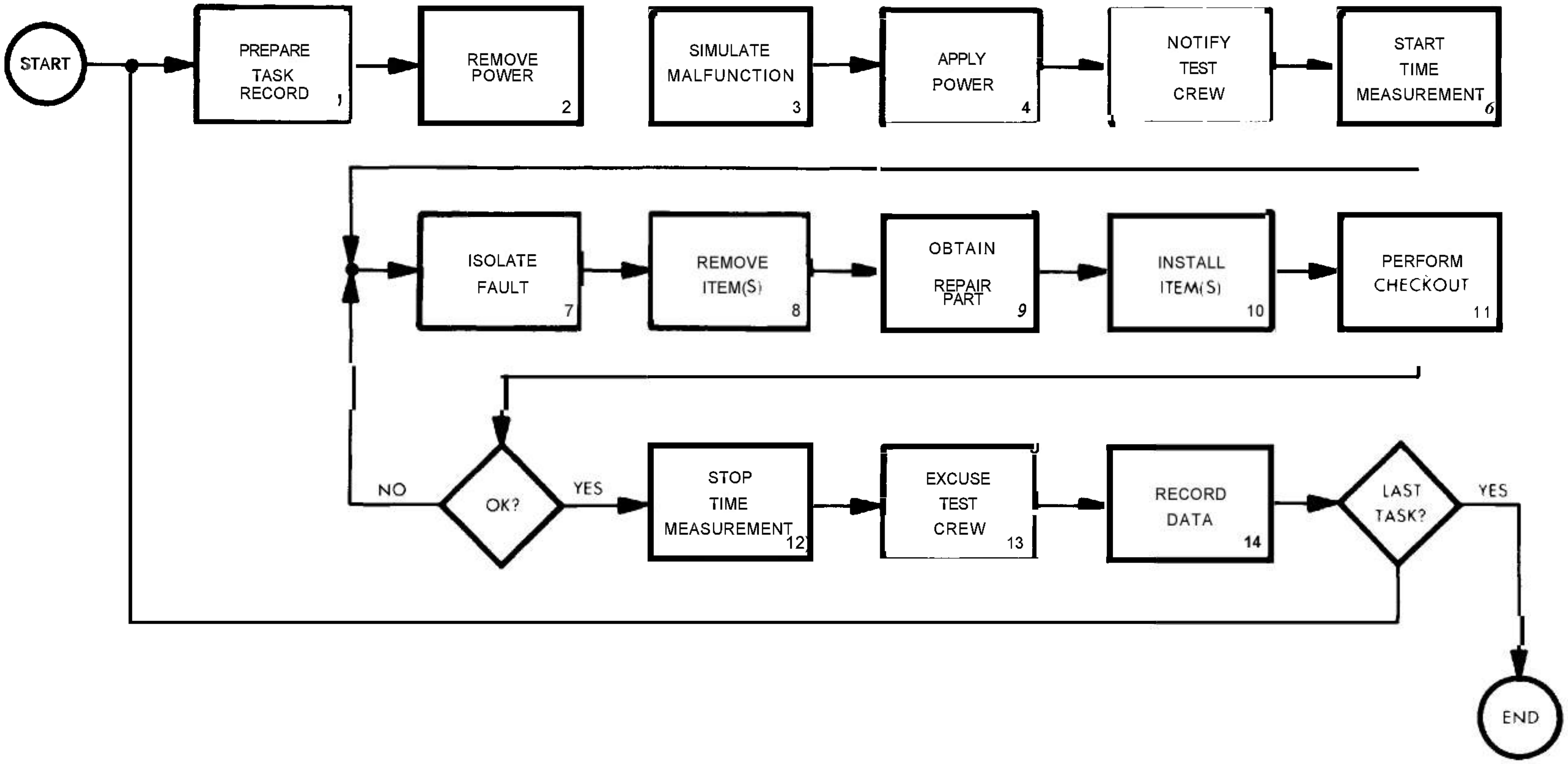


Figure 6-5. Maintainability Demonstration Sequence

The final report need not be unnecessarily detailed, since reference can be made to the maintainability demonstration test plan. The following is a possible format for the report:

a. Introductory Section. A summary of test objectives, including identification of equipment, manufacturer, contract number (if applicable), numerical requirements, demonstration site, and review team members.

b. Test Conditions. A summary of the test conditions, including maintenance personnel, with particular reference to deviations from the maintainability demonstration plan.

c. Test Procedures. A brief review of the proceedings of the demonstration test, noting particular problems and means taken to overcome them.

d. Test Results. A summary of the observed data and the results of the analysis made for decision purposes.

e. Discussion. A discussion of the test results and analysis, along with qualitative findings of the review team and maintenance team. Deficiencies in test design and procedures should be noted here, as well as deficiencies in the maintainability design and procedures associated with the equipment under test.

f. Recommendations. A specific recommendation for acceptance or rejection of the equipment under test and other recommendations for improvement in equipment, procedures, or test design.

6-3.5 RELATEDACTIVITIES

Maintenance engineering analysis data developed prior to a maintainability demonstration provide virtually all of the information required to stratify samples and determine task frequency within each stratum. These data, coupled with dynamic simulation or manual random sampling, can be used to simulate a maintainability demonstration and develop predicted values for the results of an actual test. Maintenance data from similar deployed materiel can be used to develop a second set of predicted data.

If the foregoing sets of data are developed before a maintainability demonstration and are reasonably equal, a baseline is provided with which to assess demonstration results. A wide variance between predicted and actual values would be cause for a thorough analysis of all factors bearing on the demonstration.

If the demonstration test results are unsatisfactory, and the cause is isolated to either materiel or support subsystem design deficiencies, alternatives must be formulated and tradeoffs conducted. Materiel deficiencies may be associated with fault isolation, accessibility, safety, etc. Support deficiencies may be associated with technical publications, inadequate quality and quantity of skills, etc.

6-4 ANALYSIS TECHNIQUES (Ref. 9)[1]

In making many important decisions, it is necessary to predict the values of unknown variables. Most such predictions of population parameters are made on the basis of sample statistics derived from a number of individual observations of the population members. Sometimes, data are available from a number of sources and represent a number of samples of individual observations. There is usually some question as to whether these samples represent a common homogeneous population or represent populations that are significantly different. Sometimes, knowledge of one factor may be used to make a better prediction of another. This discussion investigates how the knowledge of the relationship betweeh two variables may be applied so that information regarding one of the variables can be used to predict the value of the other. The techniques discussed fit into the three broad categories of regression analysis, correlation analysis, and analysis of variance and significance testing.

Regression and correlation analysis comprises a body of statistical methodology that investigates the "association" between variables. In par. 6-2.10, one form of statistical inference, using the sample mean $\bar{X}$ to estimate the value of the population mean μ was investigated. Another kind of inference, hypothesis testing and tests for significance, uses sample means to test a hypothesis about a population mean, and may be used along with the F distribution statistic to compare two population means. A third kind

[1]From *Statistics for Modern Business Decisions* by Lawrence L. Lapin, © 1973 by Harcourt Brace Jovanovich, Inc. and reproduced with their permission.

of statistical inference, the chi-square χ^2 tests, uses the contingency table to determine whether there is statistical dependence (or independence) between two quantitative variables. Such a test is concerned with association, but it does not say how strongly or in what manner two variables are related. Regression and correlation analyses provide both these kinds of information, since they deal with variables having values that may be ranked numerically.

Regression analysis tells how one variable is related to another. It provides an equation wherein the known value of one variable may be used to estimate the unknown value of another. When several variables are used to make a prediction, the technique used is called multiple regression.

Correlation analysis tells the degree to which two variables are related. It is useful in expressing the "efficiency" achieved in the use of one variable to estimate the value of another. It also can identify which factors of a multiple-characteristic population are highly related, either directly or through a common connection to another variable.

Regression is discussed for a linear relationship between two variables, where they are interrelated by an equation for a straight line. Consideration is also given to nonlinear relationships. Correlation analysis is discussed as an extension of regression analysis.

The analysis techniques discussed here have one purpose in common. That common purpose is to allow prediction of some population parameters from sample statistics within the confidence limits dictated by the statistical data available. These techniques are based upon established statistical and probability thedries.

The ultimate purpose of any analysis is the summarization or generalization of available data such that predictions can be made of the values of unknown variables, sometimes based on the values of known or readily available variables. This process provides the information required for intelligent decision making.

It is very important to understand that the analysis techniques discussed here will not provide magic, automatic solutions to all data analysis problems. These techniques are only tools that will aid the maintenance analyst in making inferences about population parameters based on sample statistics with some determinable degree of accuracy and confidence.

6-4.1 DESIGN OF EXPERIMENTS

An experiment is defined as the act or operation designed to discover, test, or illustrate a truth, principle, or effect, especially one intended to confirm or disprove something that is still in doubt; a method of controlled testing and direct observation under stated conditions.

For purposes of this discussion, the experiment will be considered the ultimate source of input data required for an analysis. It may be for a performance test, a maintainability demonstration, the collection of tests from which data have been accumulated for a maintenance engineering analysis data system, or merely a questionnaire in which related data elements are recorded based on previous experience or experimental techniques. The essential parts of each of these experiments is a Sample consisting of a number of data elements (repair times, replacement rates, unit costs, etc.), each of which is the result of an observation. The number of observations in each sample is referred to as the sample size n. Methods of determining the required sample size for a given confidence level and standard deviation are discussed in par. **6-2.10.** Along with these essential samples of observations or observed data elements may be other data elements that are related to these basic data elements (system complexity, deployment environment, generic failure rates, etc.) and may be used to estimate population prediction parameters.

It is important and, in some cases, essential, to know the number of observations in the sample from which statistics have been derived. Although any population distribution may be described in terms of its central tendency μ and its dispersion σ, these two parameters must be estimated, in most cases, by the corresponding sample statistics for the mean $\overline{X}$ and standard deviation s computed from a sample of finite size n. It is apparent from Eq. 6-8 that fer a given interval of accuracy k in estimating the population mean, the confidence level ϕ increases as the sample size n increases. This fundamental principle emphasizes the importance of having an adequate sample size.

There are, however, many factors that result in physical and economic limitations of the number of observations comprising the sample, and these factors must be considered in designing any experiment. In many cases, the time required to obtain sample data is such that the analysis results become obsolete or of little value. In such cases, the utility of the analysis results must be weighed on a time scale consistent with the possible number of sample observations. Likewise, the cost of obtaining a given number of sample observations must be weighed against the possible economic gains or the economic risks involved in not obtaining sufficient confidence and accuracy.

6-4.2 ANALYSIS OF VARIANCE AND SIGNIFICANCE TESTING

Analysis of variance and significance testing are useful statistical tools in making decisions regarding the significance of observed differences in data samples. By use of these techniques, it is possible to determine whether observed differences are due to underlying population differences or to chance variations in the data.

6-4.2.1 Tests for Significance

Some decisions require the comparison of populations. The comparison usually involves the population mean, but also can involve a proportion such as the proportion of items failed or the proportion of failed ,items repaired at each maintenance level. The example that follows illustrates the comparison of two population means, using two independent samples.

The Army is contemplating starting a training program for a new piece of diagnostic equipment being fielded. The current procedure is to assign a qualified trainee to operate the equipment, leaving him to "sink or swim". The using command, believing the proposed training program to be an unnecessary and expensive frill, wants some evidence that the program will improve the quality of maintenance support.

A test is proposed whereby two separate groups of trainees will be compared. Group B trainees will undertake the new program, while group A trainees will go right to work. (The group subject to the new procedure sometimes is referred to as the experimental group, and the other is called the control group.) The repairmen are to be chosen for the two groups and assigned to repair locations on a random basis so that each group will have the same number of repair stations of various levels of difficulty. The criterion by which the two training approaches will be evaluated is the mean percentage of change in the number of defective units correctly diagnosed by each member of each group over a 3-month period. The mean number of units diagnosed (sample statistics) will be denoted by $\overline{X}_A$ and $\overline{X}_B$ for the respective groups representing the means (population parameters) of μ_A and μ_B, respectively. Since the using command requires evidence to establish the superiority of the new method, the following hypotheses are tested:

H_0: $\mu_A \geq \mu_B$ (present method at least as good)

H_1: $\mu_A < \mu_B$ (proposed method significantly better)

Letting $D = \mu_A - \mu_B$, these may be expressed as

$$H_0: D \geq 0$$
$$H_1: D < 0$$

The stated hypotheses indicate that the test will be a lower-tail test. This means that the area of concern is that proportion of the area under the normal curve that lies to the left of the mean and below the critical value defined for acceptance of *No,* the null hypothesis. By contrast, an upper-tail test would be concerned with the proportion of the area that lies to the right of the mean and above the critical value for acceptance of H_0. A two-tail test is concerned with both the upper and lower tails and includes two critical values, one above the mean and one below the mean. The null hypothesis H_0 always represents the assumption of no significant difference, while the alternate hypothesis, H_1, represents the assumption that the difference is significant. Rejection of H_0 requires acceptance of H_1.

The appropriate test statistic d is the difference between the corresponding sample value.

$$d = \overline{X}_A - \overline{X}_B \qquad (6\text{-}11)$$

We use d^* to denote the critical value for the test statistic. The following decision rule is appropriate here:

Accept H_0 (retain the present procedure) if $d \geq d^*$.

Reject H_0 (adopt the proposed procedure) if $d < d^*$.

The sampling distribution of d must be determined in order to find d^*. As the standard deviations for the populations are unknown, they must be estimated from the sample results. The sampling distribution of X_A and X_B may be approximated by the normal curve if the sample size is sufficiently large (usually 30 or more). Since samples are chosen independently, d also will be distributed normally, with mean

$$D = \mu_A - \mu_B$$

and standard deviation

$$\sigma_d = \sqrt{\frac{(\sigma_A)^2}{n_A} + \frac{(\sigma_B)^2}{n_B}} \tag{6-12}$$

where σ_A and σ_B are the standard deviations of the populations of the percent changes in units diagnosed that would prevail under the respective training procedures. Here, n_A and n_B denote the sample sizes (number of repairmen) of the respective groups. (These refer to the number of trainees completing the 3-month experiment. Those repairmen dropping out are not counted.) Letting the sample standard deviations, denoted by s_A and s_B, be estimators of σ_A and σ_B, the following estimate of s_d is determined:

$$s_d = \sqrt{\frac{(s_A)^2}{n_A} + \frac{(s_B)^2}{n_B}} \tag{6-13}$$

The normal deviate z_α corresponding to an upper-tail area equal to the significance level α is related to d^* and s_d by:

$$z_\alpha = \frac{d^*}{s_d}$$

and therefore, the critical value may be obtained from:

$$d^* = z_\alpha \sqrt{\frac{(s_A)^2}{n_A} + \frac{(s_B)^2}{n_B}} \tag{6-14}$$

Suppose the using command wants only a 0.05 chance of assuming the cost of the new training program when it is not better. Then $\alpha = 0.05$, and $z_\alpha = z_{0.05} = -1.64$ (Table 6-1). The groups each have 30 trainees finish the 3-month experiment. The results are tabulated in Table 6-4. By use of these data, d^* from Eq. 6-14 is:

$$d^* = (-1.64) \sqrt{\frac{25.64}{30} + \frac{25.85}{30}} = -2.15$$

Since the test statistic has the value by Eq. 6-11

$$d = \overline{X}_A - \overline{X}_B = 3.267 - 5.267 = -2.00$$

which is larger (more positive) than $d^* = -2.15$, hypothesis H_0 that the new training method is no improvement must be accepted.

The procedure illustrated in this example may be adapted when either an upper-tail or a two-tail test is appropriate. With the upper-tail test, z_α will be positive, and the critical value is calculated from Eq. 6-14. For a two-tail test, there are two critical values, d^*_1 and d^*_2. The normal deviate $z_{\alpha/2}$ is found that corresponds to an upper-tail area under the normal curve equal to $\alpha/2$. The critical values are then calculated from:

$$d^*_2 = z_{\alpha/2} \sqrt{\frac{(s_A)^2}{n_A} + \frac{(s_B)^2}{n_B}} \tag{6-15}$$

$$d^*_1 = -d^*_2$$

This procedure also may be used to determine if the data taken from several sources and constituting several independent samples are representative of the same homogeneous population and, as such, may be combined into one overall sample, or represent samples from populations that are significantly different and should be analyzed separately.

TABLE 6-4. TEST RESULTS BASED ON INDEPENDENT SAMPLES

Group A			Group B		
Trainee	Percentage Change, X_A	$(X_A)^2$	Trainee	Percentage Change, X_B	$(X_B)^2$
1	−2	4	1	3	9
2	−10	100	2	14	196
3	0	0	3	10	100
4	7	49	4	−8	64
5	6	36	5	7	49
6	−3	9	6	−4	16
7	7	49	7	7	49
8	7	49	8	0	0
9	6	36	9	8	64
10	12	144	10	5	25
11	5	25	11	4	16
12	11	121	12	8	64
13	2	4	13	5	25
14	3	9	14	10	100
15	3	9	15	12	144
16	6	36	16	6	36
17	3	9	17	12	144
18	6	36	18	5	25
19	1	1	19	8	64
20	11	121	20	5	25
21	9	81	21	−3	9
22	4	16	22	7	49
23	0	0	23	10	100
24	−2	4	24	3	9
25	−5	25	25	−1	1
26	5	25	26	5	25
27	3	9	27	5	25
28	−5	25	28	−2	4
29	4	16	29	9	81
30	4	16	30	8	64
	98	1,064		158	1,582

TABLE 6-4. TEST RESULTS BASED ON INDEPENDENT SAMPLES (Cont'd)

Group A			Group B		
Trainee	Percentage Change, X_A	$(X_A)^2$	Trainee	Percentage Change, X_B	$(X_B)^2$

$$\left.\begin{aligned}\bar{X}_A &= \frac{\Sigma X_A}{n_A} = \frac{98}{30} = 3.267\\ \bar{X}_B &= \frac{\Sigma X_B}{n_B} = \frac{158}{30} = 5.267\end{aligned}\right\}\text{ by Eq. 6-2}$$

$$\left.\begin{aligned}(s_A)^2 &= \frac{\Sigma(X_A)^2 - n_A(\bar{X}_A)^2}{n_A - 1} = \frac{1{,}064 - 30(3.267)^2}{30 - 1} = 25.64\\ (s_B)^2 &= \frac{\Sigma(X_B)^2 - n_B(\bar{X}_B)^2}{n_B - 1} = \frac{1{,}582 - 30(5.267)^2}{30 - 1} = 25.85\end{aligned}\right\}\text{ by Eq. 6-4}$$

6-4.2.2 Analysis of Variance

The foregoing discusses tests that compare two population means by investigating differences among sample results obtained from each population. When more than two populations are involved, such tests are inadequate. Suppose, for example, that we wish to compare the mean repair turnaround time for a group of unit replaceable items at three different repair locations. By use of the testing procedures of par. 6-4.2.1, comparisons could be made of the repair turnaround times of location 1 versus location 2, location 1 versus location 3, or location 2 versus location 3; but simultaneous comparisons of all populations would not be possible.

We will now describe one method for simultaneously testing hypotheses regarding several populations, in particular to determine if they have the same mean (i.e., the population means are not significantly different). In doing this, we will analyze samples taken from each population. Our testing procedure will be to ferret out significant differences among the Sample means by investigating variances.

In comparing several population means by indirect use of samples, our null hypothesis is that the population means are identical. Using samples obtained from each population, we will calculate a test statistic summarizing differences among samples to provide a basis for rejecting or accepting the null hypothesis. The same procedures may be applied to a related problem of determining whether or not several samples actually represent a common population.

This type of problem and the related statistical procedures are introduced by means of the following detailed example that compares the means of three populations. The system support manager at a missile test range in the West is concerned with the choice of alternative methods of transportation of rush repair orders for small assemblies repaired in the East. In the past, he has, on occasion, used all of the following methods: ordinary mail, air freight, and handcarry by personnel on business trips. He has been unable to determine from his records which method is quickest. Therefore, he wishes to apply statistical techniques in order to see whether or not there is a significant difference in turnaround time of repaired assemblies under the various transportation methods.

A random sample of previous rush repair orders is selected for a detailed analysis to determine elapsed time between sending a defective assembly and receipt of the repaired assembly. The times obtained for each of the three methods are provided in Table **6-4.** The columns provide the sample observations obtained for each method of transportation. Each row represents a different observation for each mode of transportation. Letting i refer to the ith row and j the jth column, we can express the ith sample observation in the jth sample by X_{ij}. For example, $X_{23} = 4$ (the second observation of the third sample group, delivery by air freight). We denote the mean of each sample by the average of the entries in its column:

$$\bar{X}_j = \frac{\sum_i X_{ij}}{n_j} \quad \textbf{(6-16)}$$

where n_j = size of the jth sample with $j = 1$, 2, ..., m (number of samples). The subscript i under the summation sign means that we are summing by rows the entries in the jth column. Notice that the samples have different sizes. We have $n_1 = 6$, $n_2 = 5$, and $n_3 = 7$. The mean of the combined samples, called the grand mean and denoted by $\bar{\bar{X}}$ (X double bar), is calculated from:

$$\bar{\bar{X}} = \frac{\sum_j \sum_i X_{ij}}{n} \quad (6\text{-}17)$$

where the total number of observations is

$$n = \sum_j n_j \quad \textbf{(6-18)}$$

and the double summation means that the total is obtained by first summing the row entries separately for each column and then summing these column totals. (See Table **6-5** for an example of this calculation.)

The system support manager wishes to determine if the three populations of turnaround times of rush repair orders are significantly different. If so, he may find it advantageous to emphasize one means of transportation over the other two. Let μ_1 represent the mean time for mail and μ_2 and μ_3 denote the mean times for handcarry and air freight, respectively. We may then express the appropriate null hypothesis, that the population means are identical, as:

$$H_0: \mu_1 = \mu_2 = \mu_3$$

The alternative hypothesis is simply that the population means are not equal, i.e., at least one pair of μ_j's differ.

As with any testing problem, a test statistic is desired that will **(1)** highlight the differences between the sample results and what would be expected under the null hypothesis, and **(2)** have a convenient sampling distribution by which to measure the effect of sampling error. As we have seen, the amount of sampling error may be conveniently established from the variability of the sample results. We may also use the variability of the results to express differences. For instance, if several values are very different, then we have seen that their dispersion, expressed by the variance, will be greater than if the values are very nearly the same. When many values are involved, their collective differences can be summarized by the variance of their distribution.

Since we are dealing with several populations, we can use the sample statistics to estimate three kinds of variability. They are (1) the variation within each sample, **(2)** the variation between samples, and **(3)** the total variation of all sample observations without regard to sample grouping. We desire a statistic that incorporates all these types of variability so that there will be efficient utilization of sample information.

Under the null hypothesis, all the samples are taken from populations having the same mean. We shall make the additional assumption that their populations have identical distributions. This conveniently allows us to treat each sample as a different group of observations from the same population.

We use the variance primarily because of its convenient mathematical properties. Recall that the variance is the mean of the squared

TABLE 6-5. SAMPLE RESULTS OF TRANSPORTATION TIMES

Sample Observation	(Method of Transportation) Time in Days (1) Mail	(2) Handcarry	(3) Air Freight
1	3	5	2
2	4	2	4
3	5	9	6
4	3	7	2
5	3	7	3
6	3	--	3
7	--	--	1
Totals	21	30	21

Means:

$$\bar{X}_1 = \frac{21}{6} = 3.5$$

$$\bar{X}_2 = \frac{30}{5} = 6.0$$

$$\bar{X}_3 = \frac{21}{7} = 3.0$$

$$\bar{\bar{X}} = \frac{21 + 30 + 21}{6 + 5 + 7} = 4.0$$

deviations of the observations from their mean. As a preliminary step in presenting our test statistic, we consider the sum of the squared deviations, whjch we shall refer to as SS.

To calculate the within-group SS, we first find the group mean. This mean is subtracted from each of the observed values in its group. The differences are then squared and summed together for all groups. Table 6-6 shows the calculations for this example. The first three columns relate to the first sample group. For brevity, only the squared differences have been included for the second and third sample groups. In general we may calculate the within-group sum of squares, denoted by SS_w, from:

$$SS_w = \Sigma\Sigma\,(X_{ij} - \bar{X}_j)^2 \qquad (6\text{-}19)$$

The between-group SS provides a summary of the variability between the sample means. This is calculated in Table 6-5 for our example. A general expression for the calculation, which we denote by SS_b, is:

$$SS_b = \Sigma\, n_j\,(\bar{X}_j - \bar{\bar{X}})^2 \qquad (6\text{-}20)$$

In order that each observation will be counted exactly once, the squared terms in the sum are multiplied by the respective group size n_j.

Had we initially ignored the groupings of the sample observations, we could have determined the SS for a single sample. The results obtained, called the total sum of squares and denoted by SS_t, may be determined from:

$$SS_t = \Sigma\Sigma\,(X_{ij} - \bar{\bar{X}})^2 \qquad (6\text{-}21)$$

Using the values in Table 6-4, we calculate SS_t for our 18 observations:

$$SS_t = (3 - 4)^2 + (4 - 4)^2 + \ldots + (1 - 4)^2 = 76$$

TABLE 6-6. SUM OF SQUARES CALCULATIONS FOR TRANSPORTATION SAMPLES

i	X_{i1}	$X_{i1} - \bar{X}_1$	$(X_{i1} - \bar{X}_1)^2$	$(X_{i2} - \bar{X}_2)^2$	$(X_{i3} - \bar{X}_3)^2$
1	3	−0.5	0.25	1	1
2	4	0.5	0.25	16	1
3	5	1.5	2.25	9	9
4	3	−0.5	0.25	1	1
5	3	−0.5	0.25	1	0
6	3	−0.5	0.25	---	0
7	--	---	---	---	4
	Totals	0	3.50	28.00	16.00

$$SS_w = \Sigma\Sigma (X_{ij} - \bar{X}_j)^2$$
$$= 3.5 + 28 + 16 = 47.5$$
$$SS_b = \Sigma n_j (\bar{X}_j - \bar{\bar{X}})^2$$
$$= 6(3.5 - 4)^2 + 5(6.0 - 4)^2 + 7(3.0 - 4)^2$$
$$= 28.5$$

Notice that if we add the within-group and the between-group SS values, we. get the same results:

$$SS_w + SS_b = 47.5 + 28.5 = 76$$

In general, it can be shown mathematically that

$$SS_t = SS_w + SS_b \tag{6-22}$$

for any set of sample results.

Eq. 6-22 shows that the two components of total variation are the unexplained SS_w and the explained SS_b. Our task is to determine whether or not the explained variation is sufficiently significant to warrant rejecting the null hypothesis.

Up to this point, we have looked at two kinds of variability expressed by the degree to which the sample results deviate from what is expected when the null hypothesis is true. This may be done by comparing the variability within and between groups. Regardless **of** whether or not H_0 is true, we should expect some chance variation within each sample, since this is natural for any random sampling experiment. But under H_0, that the population means are identical for each method of transportation, the amount of variation between groups should be small. Therefore, under the null hypothesis, the two kinds of variability should be about the same.

In comparing the within-group and between-group variations, it will be convenient to focus on their ratio. Although other types of comparison could be made, a straightforward sampling distribution for the resulting statistic is available when one measure of variability is divided by the other.

We cannot immediately divide the sums of squares. Recall that SS_w is the sum **of** n (18 observations, in our example) squared differences, while m (three groups, in our example) squares are used to calculate SS_b. Each SS value must be converted into an average before the two are comparable. We then have sample variances, which we shall call mean squares to avoid confusion with the population variances. Mean squares may be viewed as estimators of the population variances, which are equal to a common σ^2 under the assumption that the samples are taken from identical populations (H_0 is true). These estimators are unbiased when the proper divisors are chosen. We express the within-group mean square as

$$MS_w = \frac{SS_w}{n - m} \tag{6-23}$$

In a similar manner, we define the between-group mean square as

$$MS_b = \frac{SS_b}{m - 1} \tag{6-24}$$

In our repair turnaround time example, n = 8 and m = 3. Using the sums of squares defined previously, we obtain the mean squares:

$$MS_w = \frac{47.5}{18 - 3} - 3.17$$

$$MS_b = \frac{28.5}{3 - 1} = 14.25$$

Note that the between-group mean square is more than four times as large as the within-group value. Under the null hypothesis of identical population means, they should be very nearly the same. Such a large difference seems unlikely under the null hypothesis, and it may be "explained" by different population means. We need yet to determine just how unlikely a discrepancy this size would be under the hypothesis of equal means.

We may now calculate the ratio of the mean squares, called the F statistic, using it as our test statistic:

$$F = \frac{MS_b}{MS,} = \frac{SS_b/(m - 1)}{SS_w/(n - m)} \tag{6-25}$$

For our example, we calculate this to be

$$F = \frac{14.25}{3.17} = 4.50$$

Under the null hypothesis, we should expect values for F to be close to 1, because MS_b and MS_w are both unbiased estimators of the common population variance σ^2. In order to establish a decision rule, we must establish the sampling distribution of this test statistic. From this, we can find a critical value that will tell us whether or not the calculated value of F is large enough to cause rejection of the null hypothesis. The probability distribution we use is called the F distribution. Under the proper conditions, we may use the F distribution to obtain probabilities for possible values of F. There are two parameters describing the F distribution. These parameters relate to the number of observations involved and the relations between them, and are referred to as degrees of freedom. The F distribution has two kinds of degrees of freedom, owing to our use of a ratio to define our test statistic. One type of degree of freedom is associated with the numerator of the test statistic, the other with the denominator.

We may view the $n - m$ divisor used in calculating MS_w as the number of degrees of freedom associated with using MS_w to estimate σ^2. This is due to the fact that in calculating the sum of squares, each term involved an $\bar{X}_j$, which was calculated from the X_{ij} values. For a given fixed value of $\bar{X}$ only $n_j - 1$ of the X_{ij}'s are free to assume any value, the last one being explicitly determined by all the others. For m groups, then, the number of free variables is only $\Sigma(n_j - 1) = n - m$.

The number of degrees of freedom in using MS_b to estimate σ^2 is $m - 1$. Here, getting the sum of squares involves calculation of $\bar{\bar{X}}$, which may be expressed in terms of $\bar{X}_j$'s. For a fixed value of $\bar{\bar{X}}$, all but one of the $\bar{X}_j$'s are free to vary.

The rule for the pair of degrees of freedom for the F distribution is:

$$\begin{aligned} \text{numerator} &= m - 1 \\ \text{denominator} &= n - m \end{aligned} \tag{6-26}$$

where m = the number of samples and n = the combined sample size. In our example, m = 3 and n = 18, so that we obtain the following degrees of freedom:

For the numerator: 3 – 1 = 2

For the denominator: 18 – 3 = 15

The F distribution curve is positively skewed, with possible values ranging from zero to infinity. There is a different distribution for each degrees-of-freedom pair. Since the F distribution is continuous, probabilities for the Values of F are provided by the area under the curve in the same manner as with the normal distribution. The critical values for upper-tail areas under the F distribution are provided in many books of statistical tables. Table **6-7** provides the values for F_α that correspond to a given upper-tail area α and a specified degrees-of-freedom pair. For each value of denominator degrees of freedom, the upper line shows values for $F_{0.05}$ (for 95 percent confidence) and the lower line shows values for $F_{0.01}$ (for 99 percent confidence).

The decision rule for the F statistic will reject the null hypothesis when large values of F are obtained. These will all be greater than one, since only then does the between-group mean square MS_b deviate significantly from the within-group mean square MS_w. The decision rule will be:

Accept H_0 if $F \leq F_\alpha$

Reject H_0 if $F > F_\alpha$

F_α is the critical value for the desired level of significance α. In our example, suppose that a value of α = 0.05 is selected. The decision rule would be applied by selecting the value $F_{0.05}$ = **3.68** from Table **6-7** (numerator = **2;** denominator = 15) and comparing it with F = 4.50. Since 4.50 > **3.68,** the null hypothesis is rejected, and it is concluded that the methods of transportation are significantly different. Had the value of α been set at 0.01, $F_{0.01}$ = **6.36** would have been selected from Table **6-7,** and the null hypothesis would have been accepted since 4.50 < **6.36.**

6-4.3 REGRESSION ANALYSIS AND CURVE FITTING

The primary goal of regression analysis and curve fitting is to obtain predictions of one variable using known values of another. These predictions are made by means of an equation such as $Y = A + BX$, $Y = AB^X$ or $Y = AX^B$, which provides the estimate of an unknown variable Y when the value of another variable X is known. Such an equation is referred to as a regression equation. Unlike the results of ordinary .mathematical equations, such as $A = b \times h$ for the area of a rectangle, we cannot be absolutely certain about the value of Y obtained from the regression equation. This is because of the statistical variability inherent in most variables encountered in data collection and analysis problems. Thus, predictions made from regression equations are subject to error, so that these are only estimates of the true, real-life value.

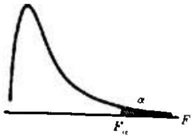
Regression analysis begins with a set of data involving pairs of observed values, one number for each variable. From these, a regression equation will be determined. Because the use of sample data gives rise to sampling error, accuracy of the estimates provided by the regression equation will depend upon the sample size and the variability of the sample data.

The first step in regression analysis is to plot the value pairs as points on a graph. The horizontal axis corresponds to values of the variable X and the vertical scale represents Values of the variable Y. Table **6-8** shows an example of paired values, and Fig. **6-6** shows the graph of these values. The points obtained in Fig. **6-6** are spread in an irregular pattern. For this reason, such a plot is referred to as a scatter diagram.

The next step is to find a suitable function to use for the regression equation, which will provide the predicted value for Y for a given value of X. The clue in finding an appropriate regression equation is the general pattern represented by the points on the scatter diagram. **A** cursory examination of the data in the example indicates that a straight line, like that shown in Fig. **6-6,** might provide a meaningful summary of the information provided in the shipment data. It seems to "fit" the rough pattern of scatter by the data points.

The linear relationship is conceptually the simplest. The general equation for a straight line is $Y = A + BX$. The constant A is the value for Y obtained when X = 0, so that $Y = A + B(0) = A$, and is referred to as the Y intercept. The constant B is the slope of the line, representing the change in Y for a given change in X. It must be emphasized that a straight line is not always an appropriate function relating Y and X. In most cases, however, it is possible to transform the functional relationship into a form easily accommodated by

TABLE 6-7. *F* DISTRIBUTION (Ref. 7)



Degrees of Freedom in Denominator	1	2	3	4	5	6	7	8	9	10	11	12
1	161	200	216	225	230	234	237	239	241	242	243	244
	4,052	4,999	5,403	5,625	5,764	5,859	5,928	5,981	6,022	6,056	6,082	6,106
2	18.51	19.00	19.16	19.25	19.30	19.33	19.36	19.37	19.38	19.39	19.40	19.41
	98.49	99.00	99.17	99.25	99.30	99.33	99.36	99.37	99.39	99.40	99.41	99.42
3	10.13	9.55	9.28	9.12	9.01	8.94	8.88	8.84	8.81	8.78	8.76	8.74
	34.12	30.82	29.46	28.71	28.24	27.91	27.67	27.49	27.34	27.23	27.13	27.05
4	7.71	6.94	6.59	6.39	6.26	6.16	6.09	6.04	6.00	5.96	5.93	5.91
	21.20	18.00	16.69	15.98	15.52	15.21	14.98	14.80	14.66	14.54	14.45	14.37
5	6.61	5.79	5.41	5.19	5.05	4.95	4.88	4.82	4.78	4.74	4.70	4.68
	16.26	13.27	12.06	11.39	10.97	10.67	10.45	10.29	10.15	10.05	9.96	9.89
6	5.99	5.14	4.76	4.53	4.39	4.28	4.21	4.15	4.10	4.06	4.03	4.00
	13.74	10.92	9.78	9.15	8.75	8.47	8.26	8.10	7.98	7.87	7.79	7.72
7	5.59	4.74	4.35	4.12	3.97	3.87	3.79	3.73	3.68	3.63	3.60	3.57
	12.25	9.55	8.45	7.85	7.46	7.19	7.00	6.84	6.71	6.62	6.54	6.47
8	5.32	4.46	4.07	3.84	3.69	3.58	3.50	3.44	3.39	3.34	3.31	3.28
	11.26	8.65	7.59	7.01	6.63	6.37	6.19	6.03	5.91	5.82	5.74	5.67
9	5.12	4.26	3.86	3.63	3.48	3.37	3.29	3.23	3.18	3.13	3.10	3.07
	10.56	8.02	6.99	6.42	6.06	5.80	5.62	5.47	5.35	5.26	5.18	5.11
10	4.96	4.10	3.71	3.48	3.33	3.22	3.14	3.07	3.02	2.97	2.94	2.91
	10.04	7.56	6.55	5.99	5.64	5.39	5.21	5.06	4.95	4.85	4.78	4.71
11	4.84	3.98	3.59	3.36	3.20	3.09	3.01	2.95	2.90	2.86	2.82	2.79
	9.65	7.20	6.22	5.67	5.32	5.07	4.88	4.74	4.63	4.54	4.46	4.40
12	4.75	3.88	3.49	3.26	3.11	3.00	2.92	2.85	2.80	2.76	2.72	2.69
	9.33	6.93	5.95	5.41	5.06	4.82	4.65	4.50	4.39	4.30	4.22	4.16
13	4.67	3.80	3.41	3.18	3.02	2.92	2.84	2.77	2.72	2.67	2.63	2.60
	9.07	6.70	5.74	5.20	4.86	4.62	4.44	4.30	4.19	4.10	4.02	3.96
14	4.60	3.74	3.34	3.11	2.96	2.85	2.77	2.70	2.65	2.60	2.56	2.53
	8.86	6.51	5.56	5.03	4.69	4.46	4.28	4.14	4.03	3.94	3.86	3.80
15	4.54	3.68	3.29	3.06	2.90	2.79	2.70	2.64	2.59	2.55	2.51	2.48
	8.68	6.36	5.42	4.89	4.56	4.32	4.14	4.00	3.89	3.80	3.73	3.67
16	4.49	3.63	3.24	3.01	2.85	2.74	2.66	2.59	2.54	2.49	2.45	2.42
	8.53	6.23	5.29	4.77	4.44	4.20	4.03	3.89	3.78	3.69	3.61	3.55
17	4.45	3.59	3.20	2.96	2.81	2.70	2.62	2.55	2.50	2.45	2.41	2.38
	8.40	6.11	5.18	4.67	4.34	4.10	3.93	3.79	3.68	3.59	3.52	3.45
18	4.41	3.55	3.16	2.93	2.77	2.66	2.58	2.51	2.46	2.41	2.37	2.34
	8.28	6.01	5.09	4.58	4.25	4.01	3.85	3.71	3.60	3.51	3.44	3.37
19	4.38	3.52	3.13	2.90	2.74	2.63	2.55	2.48	2.43	2.38	2.34	2.31
	8.18	5.93	5.01	4.50	4.17	3.94	3.77	3.63	3.52	3.43	3.36	3.30
20	4.35	3.49	3.10	2.87	2.71	2.60	2.52	2.45	2.40	2.35	2.31	2.28
	8.10	5.85	4.94	4.43	4.10	3.87	3.71	3.56	3.45	3.37	3.30	3.23
21	4.32	3.47	3.07	2.84	2.68	2.57	2.49	2.42	2.37	2.32	2.28	2.25
	8.02	5.78	4.87	4.37	4.04	3.81	3.65	3.51	3.40	3.31	3.24	3.17
22	4.30	3.44	3.50	2.82	2.66	2.55	2.47	2.40	2.35	2.30	2.26	2.23
	7.94	5.72	4.82	4.31	3.99	3.76	3.59	3.45	3.35	3.26	3.18	3.12
23	4.28	3.42	3.03	2.80	2.64	2.53	2.45	2.38	2.32	2.28	2.24	2.20
	7.88	5.66	4.76	4.26	3-94	3.71	3.54	3.41	3.30	3.21	3.14	3.07
24	4.26	3.40	3.01	2.78	2.62	2.51	2.43	2.36	2.30	2.26	2.22	2.18
	7.82	5.61	4.72	4.22	3.90	3.67	3.50	3.36	3.25	3.17	3.09	3.03
25	4.24	3.38	2.99	2.76	2.60	2.49	2.41	2.34	2.28	2.24	2.20	2.16
	7.77	5.57	4.68	4.18	3.86	3.63	3.46	3.32	3.21	3.13	3.05	2.99
26	4.22	3.37	2.98	2.74	2.59	2.47	2.39	2.32	2.27	2.22	2.18	2.15
	7.72	5.53	4.64	4.14	3.82	3.59	3.42	3.29	3.17	3.09	3.02	2.96

(Columns 1–12: Degrees of Freedom in Numerator)

TABLE 6-8. SAMPLE OBSERVATION OF PAIRED VALUES FOR DISTANCE AND TRANSPORTATION TIME

Destination	Distance X, miles	Time Y, days
1	210	5
2	290	7
3	350	6
4	480	11
5	490	8
6	730	11
7	780	12
8	850	8
9	920	15
10	1010	12

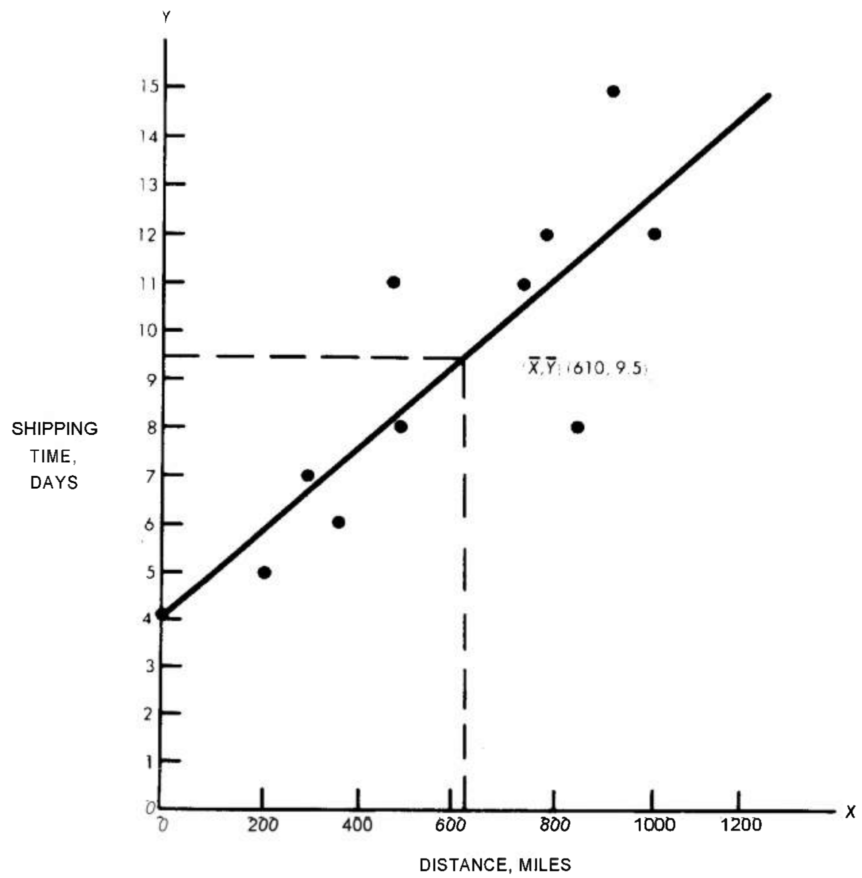


Figure 6-6. Scatter Diagram for Shipping Time Y Versus Distance X

the linear regression procedure. For example, the exponential curve of the form $Y = AB^X$ may be transformed to the linear form $\log Y = \log A + (\log B) X$. In this case, $\log Y$ is plotted on the Y axis, $\log A$ represents the Y intercept, and $\log B$ represents the slope of the line (the transformed functional relationship). Likewise, a power function of the form $Y = AX^B$ may be transformed to the linear form $\log Y = \log A + B \log X$. Here $\log X$ is treated as the independent variable and B is the slope of the transformation line.

The line used to describe the relationship between Y and X is generally obtained from sample data and is called the *estimated regression line.* It expresses the average relationship between the X and Y variables. This provides an estimate of the mean level of the dependent variable Y when the value of X is specified. Because the estimated regression line provides estimates only, we use the symbol $\overline{Y}_X$ to represent the values obtained from the linear *estimated regression equation*:

$$\overline{Y}_X = A + BX \tag{6-27}$$

The third step in regression analysis is the determination of the parameters A and B of the regression equation. The most common technique for doing this is the method of least squares. This method provides the best possible fit to a set of data, thereby providing the best possible predictions. In addition, it allows us to use statistical methodology to qualify (for instance, by confidence limits) the errors of estimation, in much the same manner as is done with the distribution of sample means.

The least squares criterion requires that a line be chosen to fit our data so that the sum of the squares of the vertical deviations separating the data points from the line will be minimum. These vertical deviations represent the amount of error associated with using the regression line to predict Y, and the value to be minimized is:

$$\Sigma(Y - \overline{Y}_X)^2 \tag{6-28}$$

where Y is the value indicated by the data, and $\overline{Y}_X$ is the value determined by the regression equation. Substituting the expression for $\overline{Y}_X$ (Eq. **6-27**) into Eq. **6-28,** the sum to be minimized becomes

$$\Sigma(Y - A - BX)^2 \tag{6-29}$$

which is a function having two unknown parameters A and B. Mathematically, it may be shown that the required values simultaneously must satisfy the following expressions, referred to as the normal equations:

$$\Sigma Y = nA + B\Sigma X \tag{6-30}$$

$$\Sigma XY = A\Sigma X + B\Sigma X^2 \tag{6-31}$$

From these relationships we can obtain the following expression for B:

$$B = \frac{\Sigma X \Sigma Y - n\Sigma(XY)}{(\Sigma X)^2 - n\Sigma(X^2)} \tag{6-32}$$

Solve Eq. **6-30** explicitly for A .

$$A = \frac{\Sigma Y - BZX}{n} \tag{6-33}$$

The value of A then can be obtained by substituting the value of B into Eq. **6-33.**

We .are now ready to find the regression equation for the transportation time data given in Table **6-8** and Fig. **6-6,** representing n **= 10** observations. In order to evaluate the expressions for A and B, we must perform a set of intermediate calculations. To find B, we must calculate ΣX, ΣY, $\Sigma(XY)$, and $\Sigma(X^2)$. Table **6-9** shows these calculations, Columns are provided for X, Y, XY, and X^2, and the sums of these values are shown at the bottoms of the columns. The values for ΣY^2, also shown, are used later in par. **6-4.4.** Using the intermediate values obtained, we can first find the value for B as follows:

$$B = \frac{\mathbf{(6110)(95) - 10(64{,}490)}}{\mathbf{(6110)^2 - 10(4{,}451{,}500)}}$$

$$- \frac{\mathbf{580{,}450 - 644{,}900}}{\mathbf{37{,}332{,}100 - 44{,}515{,}000}}$$

$$- \frac{\mathbf{-64{,}450}}{\mathbf{-7{,}182{,}900}}$$

$$= \mathbf{0.00897}$$

TABLE 6-9. INTERMEDIATE CALCULATIONS FOR OBTAINING ESTIMATED REGRESSION TIME

Distribution	Distance X	Days Y	XY	X^2	Y^2
1	210	5	1,050	44,100	25
2	290	7	2,030	84,100	49
3	350	6	2,100	122,500	36
4	480	11	5,280	230,400	121
5	490	8	3,920	240,100	64
6	730	11	8,030	532,900	121
7	780	12	9,360	608,400	144
8	850	8	6,800	722,500	64
9	920	15	13,800	846,400	225
10	1010	12	12,120	1,020,100	144
Totals	6110	95	64,490	4,451,500	993

$$\bar{X} = \frac{\Sigma X}{n} = \frac{6110}{10} = 611$$

$$\bar{Y} = \frac{\Sigma Y}{n} = \frac{95}{10} - 9.5$$

$$\Sigma XY = 64,490$$

$$\Sigma X^2 = 4,451,500$$

$$\Sigma Y^2 = 993$$

Substituting this value into Eq. 6-33, we obtain

$$A = \frac{95 - 0.00897\,(6110)}{10}$$

$$- \frac{95 - 54.807}{10}$$

$$= 4.019$$

Thus we have determined the following equation for the estimated regression line graphed in Fig. 6-6.

$$\bar{Y}_X = 4.019 + 0.00897X$$

We may now use this equation to predict the transportation time $\bar{Y}_X$ for shipment of known distance X. For purposes of error checking, the least squares regression line has two important features, ~~one of~~ which is that it goes through the point (X, Y) corresponding to the means of the observations of X and Y (Fig. 6-6). The other feature is that the sum of the deviations of the Y's from the regression line is theoretically zero (Table 6-10), i.e.,

$$\Sigma(Y - \bar{Y}_X) = 0 \qquad (6\text{-}34)$$

These facts may be used as checks to determine if any miscalculations were made in finding the equation parameters A and B.

We can analyze the variability of the data points on the scatter diagram in much the same

TABLE 6-10. COMPUTATION OF DEVIATION FROM REGRESSION TIME FOR CONSISTENCY CHECK

X	Y	$\overline{Y}_X$	$Y - \overline{Y}_X$
210	5	5.903	−0.903
290	7	6.620	0.380
350	6	7.159	−1.159
480	11	8.325	2.675
490	8	8.414	−0.414
730	11	10.567	0.433
780	12	11.016	0.984
850	8	11.644	−3.644
920	15	12.271	2.729
1010	12	13.079	−1.079
		$\Sigma\ (Y - \overline{Y}_X) =$	0.002

manner as we do with univariate data by focusing on the variance of the Y data about the regression line. The equation for this variance, the mean of the squared deviations for sample size of n, is:

$$\frac{\Sigma(Y - \overline{Y}_X)^2}{n}$$

The square root of the mean squared deviations is referred to as the standard error of the estimate about the regression line and is expressed as:

$$S_{XY} = \sqrt{\frac{\Sigma(Y - \overline{Y}_X)^2}{n - 2}} \tag{6-35}$$

The reason for subtracting 2 from n is that 2 degrees of freedom are lost because A and B, making up the expression for $\overline{Y}_X$, have been calculated from the same data.

6-4.4 CORRELATION ANALYSIS

The goal of correlation analysis is to measure the degree to which two variables are related. It is very useful as an auxiliary tool for use in regression analysis. The central focus of correlation analysis is finding a suitable index that indicates how strongly X and Y are related. The degree to which X and Y are related may be explained in terms of the magnitude of scatter about the regression line. One extreme case occurs when the amount of scatter is so great that the regression line has zero slope and is parallel to the X axis. We say that the degree of correlation is zero, since knowledge of X cannot add to the accuracy of predictions of Y. The opposite extreme is a perfect fit between Y and X observations because all the data points happen to lie on the same line.

It is convenient to summarize the scatter about the regression line with the sum of the squared deviations about the regression line $\overline{Y}_X$:

$$\Sigma(Y - \overline{Y}_X)^2$$

This may be compared to the scatter of the sample observations about their mean represented by

$$\Sigma(Y - \overline{Y})^2$$

since one estimate of Y is the mean of all observed values. Using these two values, we may construct the sample coefficient of determination to express how strongly X is associated with Y:

$$r^2 = 1 - \frac{\Sigma(Y - \overline{Y}_X)^2}{\Sigma(Y - \overline{Y})^2} \tag{6-36}$$

When X and Y have zero correlation, the regression line has a zero slope and $\overline{Y}_X = \overline{Y}$, in which case the deviations about $\overline{Y}_X$ are the same as those about $\overline{Y}$. This makes the numerator the same as the denominator, so that

$r^2 = 1 - 1 = 0$. If X and Y are perfectly correlated, then $\Sigma(Y - \bar{Y}_X)^2 = 0$ (no deviations from the line), so that $r^2 = 1 - 0 = 1$.

In actual practice, we may use the estimated regression coefficients and the intermediate value obtained in finding them to calculate r^2 from the following mathematically equivalent equation:

$$r^2 = \frac{A\Sigma Y + B\Sigma(XY) - n\bar{Y}^2}{\Sigma Y^2 - n\bar{Y}^2} \qquad (6\text{-}37)$$

This equation uses values previously obtained from regression analysis (Table 6-9) and the calculated values of A and B to yield

$$r^2 = \frac{4.019(95) + .00897(64{,}490) - 10(9.5)^2}{993 - 10(9.5)^2}$$
$$= 0.64$$

The motivation in comparing variations about $\bar{Y}_X$ to variations about $\bar{Y}$ is to show how knowledge of X can reduce errors in predicting Y. The coefficient of determination may be interpreted as the ratio of the variations in Y that are explained by the regression line $\bar{Y}_X$ to the total variation in Y about the arithmetic mean $\bar{Y}$. The total variation of Y has been shown to equal the sum of the explained and the unexplained variations:

$$(Y - \bar{Y}) = (\bar{Y}_X - \bar{Y}) + (Y - \bar{Y}_X)$$

which can be stated in words:

Total variation = explained variation and unexplained variation.

The total variation expresses the amount of vertical scatter by the data points about their mean $\bar{Y}$. This may be measured by $\Sigma(Y - \bar{Y})^2$. Likewise we use $\Sigma(Y - \bar{Y}_X)^2$ to express the unexplained variation, the magnitude of scatter about the estimated regression line. The explained variations may therefore be expressed as the difference:

$$\text{Explained variation} = \Sigma(Y - \bar{Y})^2 - \Sigma(Y - \bar{Y}_X)^2$$

If we determine the ratio of the explained to the total variation, we obtain:

$$\frac{\text{Explained}}{\text{Total}} = \frac{\Sigma(Y - \bar{Y})^2 - \Sigma(Y - \bar{Y}_X)^2}{\Sigma(Y - \bar{Y})^2}$$
$$= 1 - \frac{\Sigma(Y - \bar{Y}_X)^2}{\Sigma(Y - \bar{Y})^2} \qquad (6\text{-}38)$$

The right-hand side of the preceding equation is the sample coefficient of determination given in Eq. 6-36. In our illustration, we calculated $r^2 = 0.64$. This signifies that 64 percent of the total variation, or scatter, of the transportation times Y about the mean transportation time $\bar{Y}$ can be explained by the relationship between $\bar{Y}$ and the destination distance X, as estimated by the regression line for X and Y.

Although the rationale for using the coefficient of determination (corresponding to the variance of a normal distribution) to express the degree of relationship between X and Y is well justified, the square root of this value (corresponding to the standard deviation of a normal distribution) also is used extensively. This value is called the sample correlation coefficient r:

$$r = \sqrt{r^2} \qquad (6\text{-}39)$$

and this sample statistic is considered a point estimate of the true population parameter, called the population correlation coefficient ρ, defined as follows:

$$\rho = \sqrt{\rho^2} \qquad (6\text{-}40)$$

For the transportation data in our example, the sample correlation coefficient is

$$r = \sqrt{r^2}$$
$$= \sqrt{0.64} = \pm 0.80$$

Since the square root of a number may be positive or negative, we choose a positive sign for r to indicate that transportation time increases as rail distance increases, so that X and Y are directly related. When Y bears an inverse relationship with X, the sign of r is negative. The values for $r = \sqrt{r^2}$ may range from -1 to $+1$, and the sign of the correlation coefficient must be the same as for the slope of the regression line.

6-5 MAINTENANCE EVALUATION

Maintenance evaluation is a phase of maintenance support planning that begins in the conceptual phase and is completed prior to quantity production or procurement of the item for its initial entry into the Army inventory. It consists of maintenance engineering analysis, including teardown and test, when necessary, of early production prototype and/or development models by maintenance engineers for the purpose of:

a. Determining the most feasible method of supporting the equipment

b. Determining the definitive requirements for support resources

c. Completing maintainability analysis of selected equipments at the time of each in-process review

d. Allocating maintenance operations to the appropriate maintenance levels

e. Detecting design parameters that have an impact upon maintenance

f. Recommending design changes.

6-5.1 EVALUATION SEQUENCE AND OTHER CONSIDERATIONS

Maintenance evaluation is performed at various times throughout the materiel acquisition cycle, and in various forms. Initially, maintenance requirements are developed for the materiel based on reliability, availability, and maintainability requirements established in the required operational capability document. These requirements normally permit gross definition of the maintenance concept and maintenance resource requirements. Requirements of increasing detail are defined during the conceptual and other phases through the iterative process of analysis and/or trade-off. An analytical comparison of the top requirements, and later the definitive requirements, is made with the proposed physical hardware characteristics, and thus the foundation of the maintenance engineering analysis data system is established. Throughout further development–progressing through concept drawings, released engineering, mock-ups, engineering models, and prototypes–the maintenance engineer continually performs analysis and subsequent evaluation of the documentation against the hardware development. These iterative and sequential informal evaluations result in the identification and availability of the maintenance engineering generated or influenced portion of the technical data package in a timely manner and with a high degree of confidence in its accuracy. The maintenance engineering generated or influenced portion consists of the PMAC, technical publications, training, and identification of maintenance resource requirements. The actual evaluation or validation of the total logistic support package occurs when the physical logistic support items identified in the data system are available concurrently with the hardware to perform a physical hardware validation. The evaluation in this stage may be combined with other test programs, such as development tests, or may be conducted as a separate, formally scheduled maintenance evaluation with all identified materiel and support resources available. The result of this formal evaluation should result in minimum changes to the maintenance technical package if the informal evaluations have been conducted on the mock-ups, engineering models, and prototypes.

Since maintenance engineering analysis data are the source for identification and development of the maintenance resources to support materiel, the data are a significant and key factor to the success of a maintenance evaluation. Identification of the resources in the logistic analysis data insures the availability, accuracy, and adequacy of the materiel maintenance resources (i.e., support equipment, common and special tools, publications, test, measurement, and diagnostic equipment, training, PMAC's) to support the developed hardware.

The maintenance engineering system for a materiel program may be defined as the integrated activity resulting from maintenance engineering analysis, maintenance planning, and maintenance evaluation. This integrated activity influences the design of materiel and establishes maintenance levels and the range and depth of all support resources. The activity is a significant contributor to materiel operational or system effectiveness. All expressions for system effectiveness have availability in some form as one of their key factors. A typical expression is:

$$S.E. = (A)(D)(C)(U) \tag{6-41}$$

where

S.E. = system effectiveness, the probability that a system can successfully meet an operational demand within a given time when operated under specified conditions, or the ability of a system to do the job for which it was intended.

A = availability, the measure of the degree to which a system is in the operable and commitable state at the start of a mission when the mission is called for at an unknown random point in time. This often is called operational readiness.

D = dependability, the measure of the system operating condition at one or more points during the mission, given the system condition at the start of the mission (availability). This, often is called mission reliability.

C = capability, the measure of the ability of a system to achieve its mission performance objectives, given the conditions during the mission (dependability). This sometimes is called performance or design adequacy.

U = utilization, an adjustment or degradation factor used in the event that stresses are imposed on the system as a result of the system being used in a mission profile or environment more stringent than the one for which it was initially designed. If the system is used beyond what was intended originally, there undoubtedly will be a degrading effect on availability, dependability, and capability (Ref. 1).

Materiel availability is a function of reliability and maintenance downtime, and the downtime depends totally upon maintenance engineering decisions. Additionally, the maintenance dictated by maintenance engineering decisions directly affects reliability. Maintenance also affects the dependability and utilization factors. It may be seen that system operational effectiveness is a direct function of the effectiveness of the maintenance engineering system.

6-5.2 PHYSICAL TEARDOWN AND EVALUATION REVIEW

The physical teardown and evaluation review is a distinct task of the total maintenance evaluation effort. One of its primary purposes is to determine whether or not the logistic requirements have been met. It is performed by the developing commodity command and takes place at that point in the life cycle when developmental prototype or early commercial production hardware is available, together with all items of the maintenance test package (other than the full range of repair parts) required for the development test.

Conducting an actual physical teardown of the equipment under development at this time will validate the maintenance data contained in the PMAC's as follows:

a. Evaluate the method of supporting each end item (allocation of maintenance operations to the appropriate maintenance categories).

b. Determine definitive requirements of each element of maintenance support (special and common tools and test equipment, personnel skills, etc.)

c. Evaluate calibration and maintenance calibration procedures and develop new or improved procedures as required.

d. Detect design parameters that have an impact upon maintenance and recommend improvements.

e. Review preliminary operator and maintenance manuals for adequacy and recommend improvements as required.

f. Provide other agencies participating in the program an opportunity to evaluate their maintenance requirements and submit their comments and/or suggestions.

g. Review disassembly order and, when required, time to remove and replace.

The major disadvantage of a physical teardown is the possibility of damaging the equipment. Damage could be caused by the lack of training and tools used by the evaluation team or by special tools not being available.

The resolution of discrepancies discovered during physical teardown and evaluation is completed prior to approval for start of production. Early identification of discrepancies is necessary to assure the opportunity for correction before design has been firmly established and drawings are finalized. It is intended that results of the evaluation provide data for the development of command positions and recommendations for initiation of production.

The physical teardown and evaluation review is the nondestructive physical disassembly of a development or preproduction prototype model. Disassembly covers organizational and direct and general support maintenance levels, to the extent necessary to achieve the following objectives:

a. Verification of end item maintainability

b. Verification of adequacy of the planned elements of logistic support (maintenance test package) to include:

(1) Support and test equipment

(2) Supply support (provisioning)

(3) Transportation and handling

(4) Equipment publications

(5) Facilities (maintenance, supply, and storage)

(6) Personnel and training.

c. Verification of the Preliminary Maintenance Allocation Chart (PMAC) to assure that maintenance functions are assigned to the appropriate maintenance levels.

6-5.2.1 Physical Teardown and Evaluation Plan

The purpose of the physical teardown and evaluation plan is to provide detailed information regarding the who, what, when, where, and how of the physical teardown and evaluation. It identifies the end item and the maintenance test package items to be evaluated. A summary of the conferences, correspondence, and discussions leading up to the teardown evaluation, and a summary of the pertinent contractual provisions will be included for background information. A discussion of the constraints and limitations that have been or may be imposed should be included and may contain but are not limited to:

a. Funding, number of participating personnel, or duration of evaluation

b. Deletion of various evaluation tasks

c. Unavailability of various maintenance test package items

d. Performance of the teardown and evaluation in conjunction with other tests or evaluations.

6-5.2.1.1 *General Information*

The physical teardown and evaluation may take place at any specified location. The evaluation team performs all evaluation tasks, and records discrepancies, problems, and recommended changes. Each discrepancy, problem, and recommended change is forwarded separately to the functional office responsible for corrective action. All decisions regarding proposed changes should be completed prior to closeout of the physical teardown and evaluation.

The location(s) where the physical teardown and evaluation are to be conducted are identified and the transportation arrangements for participants are outlined. Schedules are included, indicating the planned starting and completion dates for the total evaluation, as well as for individual parts thereof. For scheduling purposes, the total evaluation should be broken down into a convenient number of parts. These may be in terms of subsystems, groups of tasks, levels of maintenance, items of the maintenance test package, etc. The information may be portrayed in the form of a tabulation or in standard time-phased chart format. General information pertaining to planned conferences, advance visits to the evaluation site, etc., also should be provided. as required.

6-5.2.1.2 *Evaluation* Team

The evaluation team concept and structure, team member skills and general responsibilities, and participating commands and agencies are described in the plan. For effective management of the team, it should be divided into task groups. Members of the groups should be technically skilled in their respective functional areas. Task groups may be organized based on equipment subsystems or logistic support items, or a combination of both. Type, size, and complexity of the systems being evaluated will dictate the breakdown and quantity of required task' groups. General responsibilities assigned to team members are:

a. Mechanic. Service, inspect, remove, and install. The equipment maintenance MOS and grade level of the mechanics should be the same as those established in the personnel and training portion of the qualitative and quantitative personnel requirements information of the support plan. In the event military personnel are not available, equivalent mechanics should participate.

b. Quality Control Specialist and Technician. Observe mechanic's operation, record discrepancies, record contract nonconformances, and suggest proposed changes to correct the discrepancies or nonconformances. These members may be engineering technicians, equipment specialists, or other civilian or military personnel with equivalent skills.

c. *Maintenance Engineer.* Evaluate discrepancy and nonconformances, and determine and record the most appropriate proposed change. Serve as task group leader.

d. Technical Publication Writer. Prepare draft changes to technical manuals to correct discrepancies.

e. Technical Recorder. Assist in preparation of discrepancy sheets, and log and process the sheets.

Appropriate commands/agencies should be requested to designate representatives to serve as evaluation team members.

6-5.2.*1*.3 Evaluation *Instructions*

Detailed instructions for the accomplishment of all evaluation tasks are contained in the plan.

Specific areas included in these instructions are review and verification of adequacy of

a. PMAC for appropriate assignment of maintenance levels

b. Preliminary technical manuals for clarity, completeness, and compatibility with the PMAC

c. Common tools and special tools and tool sets required for performance of specified maintenance functions

d. Common and special support and test equipment required for performance of specified maintenance functions

e. Repair part selection and allocation to the appropriate maintenance level

f. Predicted mechanic skill levels and number of man-hours and maintenance personnel required for specific maintenance functions.

Also, instructions should be contained in the plan pertaining to the following:

a. Sequence of performance of evaluation tasks, based on maintenance level, or functional. grouping, or any other convenient order

b. Assignment of priorities in case the evaluation has to be terminated before all tasks are completed

c. Use of multishift operation to preclude an excessively lengthy evaluation period

d. Subdivision of task groups to permit simultaneous accomplishment of several evaluation tasks

e. Provisions to preclude unnecessary repetition of tasks that may be at different levels of maintenance but are identical in nature

f. Deletion of tasks that are anticipated to yield invalid results or results already known due to similar evaluations, hardware, or design features.

The method of recording, processing, and disposing of discrepancies detected by the team during the physical teardown evaluation should be described in the plan. It also should include definitions of the discrepancies and of the decisions to be rendered regarding their disposition.

6-5.2.*1*.4 Resource Acquisition

The support required for the physical teardown evaluation should be covered in detail, including quantities, dates, and locations. This requires close coordination with the contracting officer and developer. The plan should state the arrangements which have been made or which yet have to be made to obtain all required items. The following items should be considered for inclusion in the plan:

a. Facilities. Adequate area for demonstration and testing of equipment to be evaluated. The area shall be clean and isolated from environments that may be detrimental to objective evaluation of maintenance characteristics of the materiel

b. Plant Equipment. Plant equipment—such as forklift trucks, benches, tables, racks, and all other support equipment—at appropriate locations and in sufficient quantities to support the maintenance evaluation testing of the materiel *c. Office Equipment.* Desks, chairs, file cabinets, typewriters, phones, etc.

d. Personnel. Mechanics and technical personnel to serve as advisers to the evaluation team

e. Prototype Models. Prototype or preproduction models, at appropriate locations and in sufficient quantities for expeditious conduct of maintenance evaluation

f. Maintenance Test Package Items. Test and test support items consisting of the following:

(1) *Technical Data.* Drawings, maintenance engineering analysis data, PMAC or equivalent work sheets, support subplans, and other pertinent engineering plans and reports

(2) *Technical Manuals.* Organization and direct and general support maintenance and preventive maintenance manuals

(3) *Tools and Support Equipment.* All common and special tools and test, measurement, and diagnostic equipment required to perform equipment teardown. Test equipment required for all phases of maintenance evaluation also shall be provided at appropriate locations.

(4) *Test and Calibration Equipment.* Complete maintenance calibration and calibration procedures shall be provided to insure accurate measurements and data.

(5) *Repair Parts.* A selected number of parts to replace damaged parts and to verify interchangeability

g. Special-purpose Kits. Special-purpose kits (environmental, etc.) required for maintenance evaluation demonstration and testing at the time of evaluation, in sufficient quantities for effective conduct of demonstration and tests

h. Maintenance Tasks and Skills. A maintenance task and skill analysis for use during maintenance evaluation. Justification for the specific tasks and skills recommended, and any new military occupational specialty requirement proposed, shall be included as part of the contractor's support during maintenance evaluation.

i. Human and Safety Engineering Data. Data for verification during maintenance evaluation. Special emphasis shall be placed on the safety features of the materiel to insure that no hazards exist in the use, storage, or maintenance of the materiel.

6-5.2.1.5 *Evaluation Items List*

A comprehensive list of all items to be reviewed during the teardown evaluation should be contained in the plan. The list may be in the form of a tabulation by nomenclature, part number or equivalent designation, and stock number, if available. The list should include the end item, all maintenance test package hardware and data items, and special-purpose kits. It is intended to reflect the magnitude of the evaluation and to serve as a basis for preparation of the evaluation task list.

6-5.2.1.6 *Evaluation Task List*

A detailed list of all tasks to be performed during the teardown evaluation should be contained in the plan. Primary sources of information for development of the tasks are the maintenance engineering analysis data system or the PMAC, the preventive maintenance inspection checklists, the evaluation items list, and the general checklists. The task list should include a coded cross-reference to a diagram of the end item, showing the location of items to be evaluated. The format of listing of the tasks should lend itself administratively to ready use by the evaluation team.

Table 6-11 (located at end of the chapter) contains a list of materiel design features that may be used to assist in determining tasks to be performed, as well as in making an overall evaluation of materiel. The list is also useful in making formal and informal evaluations of drawings and hardware throughout a materiel life cycle. It will be noted that many of the items in the list are qualitative maintenance parameters. In applying the list, the maintenance engineer should define the qualitative statements in terms of quantitative values whenever possible.

6-5.2.1.7 *Required Actions*

The plan should contain a listing, in chronological order, of all open actions to be accomplished in the period between publication of the plan and start of the teardown and evaluation. It should include the required action, scheduled completion date, and action office. Its major purpose is to insure that no steps are overlooked and that all planned actions are accomplished on time.

6-5.2.2 Conduct of Evaluation

The conduct of the maintenance evaluation will adhere to the following guidelines:

a. The technical supervisor will insure that all documentation and hardware are available and will designate individuals to review PMAC's, preliminary operation and maintenance manuals, and calibration and maintenance calibration procedures.

b. The individual designated to review the PMAC will specify operations to be performed and announce the tools to be used.

c. The technician will perform operations as prescribed by the PMAC's and preliminary operation and maintenance manuals.

d. Drawings, PMAC's, preliminary operation and maintenance manuals, calibration and maintenance calibration procedures, and tool and test equipment lists will be reviewed for compatibility.

e. Upon discovery of incompatibility or design deficiency, the operator will halt the operation. The operation will not be resumed until the situation has been documented and recommendations for correction made. Photographs will be made as required.

f. Representatives from all agencies will be required to sign a concurrence sheet for each major item of equipment. This concurrence will indicate agreement with all maintenance procedures, publications, tools, and test equipment for their agencies.

g. Observers will be encouraged to remain in designated areas. When an observer desires to see a particular operation or condition, he will make arrangements with the technical supervisor (time will be provided for observers to examine the equipment).

h. Observers will be encouraged to participate in discussions with the technical supervisor concerning the maintenance evaluation.

i. Disassembly of items will be limited to one of a type. When the design of an item is similar to a corresponding item, only the portion that is different will be reviewed.

6-5.2.2.1 Chunges

During maintenance evaluation, the following guidelines will be used in preparing changes:

a. Comments that make only an insignificant improvement in the system will be avoided.

b. Comments of an interrogatory nature, in lieu of providing sufficient concrete answers to the problem, will be avoided.

c. Comments based solely on differences of opinion will be avoided.

d. Comments will be grouped in two categories: general and specific. General comments are those dealing with PMAC's failing to follow specified outlines or comments dealing with changes being required in more than five places. Specific comments are those dealing with a single item that can be designated by page, paragraph, and line number.

6-5.2.2.2 Reports and Records

a. Copies of changes to PMAC's, preliminary operation and maintenance manuals, calibration and maintenance calibration procedures, and tool and test equipment lists will be furnished to participating agencies on a day-by-day basis.

b. A final report covering the complete maintenance evaluation of the materiel will be completed and ready for publication within 30 days after the evaluation is completed.

6-5.2.2.3 Events Following the Maintenance Evaluation

a. Complete testing of end item should be performed to insure that the equipment is operational.

b. The developer will be responsible for the disposition of all test specimens and material in accordance with procuring agency direction.

6-5.2.3 Physical Teardown and Evaluation Review Report

A report is prepared to provide a summary description of the total evaluation statistical data, general findings, conclusions, and specific recommendations. A typical report contains the following information. It describes the magnitude of the evaluation effort in terms of the number of participating personnel, number of tasks performed, number of man-hours spent, and starting and completion dates. Reference to the physical teardown phase is made briefly, describing to what extent the evaluation was performed in accordance with or differed from the plan. Statements of fact are contained as to the general findings in the evaluation and a list of specific conclusions (positive as well as negative) based on the findings. Recommendations based on the conclusions are made, along with separate recommendations regarding significant discrepancies that are submitted to the Defense and Army Systems Acquisition Review Councils for decision.

Examples of some typical recommendations that resulted from a maintenance evaluation review of the PERSHING power station follow.

a. Documentation. Forms were prepared that requested the contractor to take corrective action with regard to the following types of preliminary operation and maintenance manual deficiencies:

(1) Incomplete or inadequate procedures

(2) Steps out of sequence

(3) Steps missing

(4) Incorrect paragraph titles.

b. Tools. The addition of some new tools and type changes for tools presently on the PMAC were recommended as follows:

(1) Add an engine gearbox sling, workstand, and diagonal cutting pliers.

(2) Change an open end wrench to a single-socket spinner wrench, and a standard socket to a deep-well socket.

c. Equipment. The following recommendations pertain to design features and shipping instructions:

(1) Bolt rather than rivet the control cubicle door.

(2) Ship gearboxes with lifting eyes installed.

(3) Standardize the length of the bolts that attach the air conditioner to the frame.

The report also lists the names of all participants, their assignment to the various tasks and subgroups, and their agency affiliations. A statistical summary is prepared in tabular form for the end items and for each major subsystem to provide a quick overview of the results of the evaluation. A list of each discrepancy requiring further study is contained in the report. Each item is identified by a heading followed by a brief narrative description, including the reason why the study is required and whether the study is to be performed in-house or by the contractor. A list of items that could not be evaluated due to nonavailability or to planned replacement with a later configuration is contained in the report. One of the purposes of the list is its inclusion in the maintenance portion of the service test.

The report contains a detailed description of each discrepancy referred to the Systems Acquisition Review Councils. The information on each discrepancy contains all required supporting data. As a minimum, the description should contain the following:

a. A detailed presentation of the discrepancy and its impact on the system

b. The proposed change(s), estimated cost, and impact on schedules, reliability, maintainability, and performance

c. Reason for referring the discrepancy to the Systems Acquisition Review Council

d. Recommended review action.

6-5.3 DATA ANALYSIS AND UTILIZATION

Maintenance evaluations frequently result in analysis and maintenance allocation chart activities typified by the following:

a. Analysis. The extent and complexity of problems discovered during the maintenance evaluation determine the extent of subsequent analysis activities. Minor problems between participating agencies are settled during the course of the evaluation, so that no subsequent analysis is required. Major problems—those requiring major maintenance concept changes, high-cost design changes, etc.--trigger comprehensive trade-offs between alternative problem solutions. Normally, these trade-offs will be conducted by the developer. If trade-offs reveal the need for design changes, the developer will prepare and submit engineering change proposals for Army approval. After approval of the proposals, the developer will initiate hardware and documentation modifications.

b. Maintenance Allocation Chart. The MAC is modified, as required, with the validated or corrected PMAC data resulting from the maintenance evaluation and becomes a part of the organizational technical manuals.

TABLE 6-11. MAINTENANCE EVALUATION CHECKLIST

GENERAL PRINCIPLES OF MAINTAINABILITY

1. Reduce or eliminate the need for maintenance.
2. Reduce the amount, frequency, and complexity of required maintenance tasks.
3. Provide for reduction of life cycle maintenance costs.
4. Reduce the required levels of maintenance skills and the training required for them.
5. Establish maximum frequency and extent of preventive maintenance to be performed.
6. Improve information for educational programs for maintenance.
7. Reduce the volume and reading complexity of maintenance publications.
8. Provide components that can be adjusted for wear, and provide adjustment so as to preclude teardown to attain it, when practical.
9. Provide the characteristics in the commodity and its components that will result in minimum downtime.
10. Insure that simple, adequate, and satisfactory maintenance technical data are available with the equipment when delivered.
11. Provide for time studies on removal and installation of major items of equipment.
12. Provide for repair times of components. Reduce the mean time to repair.
13. Provide optimum accessibility to all equipment and components requiring frequent maintenance, inspection, removal, or replacement. Avoid hiding this equipment.
14. Provide for rapid and positive identification of equipment malfunction or marginal performance. This should include, for example, logical troubleshooting charts, in fault tree diagram form, that list potential failures and method to correct them. Associate times to perform the correction as appropriate.
15. Insure the human factor aspects are satisfactory and that location and operability of controls and manual force limitations, etc., are adequate and accessible for hand, leg, foot, and body. Provide the human engineering aspects for access to maintenance points such as electrical, pneumatic, hydraulic, lubrication, and fuel servicing.
16. Provide optimum capability to verify performance, anticipate and locate malfunctions, and perform calibration.
17. Provide for adequate, clear, and rapid identification of parts and components that may be replaced or repaired.
18. Reduce the quantities and types of tools, tool sets, and equipment necessary to maintain the whole commodity. Eliminate, whenever possible, the need for special tools.
19. Plan design of commodity to use field organizational maintenance equipment and facilities that are normally available.
20. Reduce to a minimum the number and types of repair parts and components needed to support the maintenance.
21. Insure use of military standard parts, components, types, and materials to the fullest possible extent, and identify all MIL-STD parts, components, and material with MIL-STD nomenclature.

TABLE 6-11. MAINTENANCE EVALUATION CHECKLIST (Cont'd)

GENERAL PRINCIPLES OF MAINTAINABILITY (Cont'd)

22. Use less critical materials, and less costly, rare, or difficult processes.
23. Provide for maximum interchangeability.
24. Provide maximum safety features for both equipment and personnel in the performance of maintenance.
25. Provide sufficient and adequate towing, hoisting, lifting, and jacking facilities for mobility and handling requirements. .
26. Provide for maximum storage life with minimum storage maintenance rehabilitation.
27. Reduce amount of supply support required.
28. Insure that engines/installations are rapidly replaceable as a unit with the minimum time and personnel.
29. Insure that the commodity will not be dangerous to itself or to personnel maintaining it.
30. Insure necessary environmental compatibility for the commodity (e.g., corrosion, fungus, water, salt spray, heat, cold, altitude, attitude, blown sand, snow, snow loads, and wind) on the whole and on components of the weapon, commodity, or system.
31. Insure that there are no seriously undesirable operating or maintenance characteristics affecting the maintenance personnel, or other personnel or equipment in the expected vicinity (i.e., radiological hazards, noise, etc.).
32. Provide bearings and seals of sizes and types that will require a minimum of replacement and servicing on a life cycle basis. Select adjustable items to take care of wear.
33. Provide gears of adequate size and type to satisfy all overload requirements and be suitably derated on a life cycle basis.
34. Provide for ease of inspection, replacement, and rapid adjustment in servicing of brakes and clutches, without the need of teardown.
35. Insure that all mechanical, electronic, electrical, hydraulic, and structural components are sufficiently derated to combat unexpected overload(s) that would result in an operable or degraded component and thus require maintenance.
36. Insure that advanced accessibility practices have been incorporated. These include rapid access to systems, components, and parts by use of rapid operating fasteners, covers, doors, etc., and a minimum of bolts, fasteners, etc.
37. Insure that components requiring frequent maintenance are located to preclude the need to remove other components to gain access to the specific component.
38. Provide line of sight to components, whenever possible, for routine inspection, to eliminate the need to remove other equipment(s).
39. Insure that adjustment controls are rapidly accessible.
40. Provide adjustment control locking devices.
41. Provide sufficient and adequate test points and test features, and provide ease of accessibility thereto. Test points should be capable of accepting automatic test equipment when practical.

TABLE 6-11. MAINTENANCE EVALUATION CHECKLIST (Cont'd)

GENERAL PRINCIPLES OF MAINTAINABILITY (Cont'd)

42. Insure that all test equipment and calibration equipment required for the commodity are available.
43. Provide simplified goho-go (self-diagnostic) automatic, built-in fault isolation capabilities and calibration equipment as feasible, practical, or cost-effective.
44. Insure that there is sufficient storage for spare modules (components/assemblies) and that modules are stored in the commodity. This applies to fuzes and other attrition items.
45. Insure that batteries are located for rapid servicing and replacement, and are vented as required.
46. Insure that weapons, systems, commodities, and special parts are repairable, except throwaway components and modules.
47, Insure that adequate and sufficient guards are installed over dangerous moving mechanisms.
48. Insure that adequate protection from dangerous electrical shock is provided for maintenance personnel.
49. Insure that no toxic fumes are emitted that will affect maintenance personnel.
50. Insure that all items are incorporated that will render the item explosionproof, when required.
51. Insure that fire extinguishing equipment is installed and adequate.
52. Insure protection of personnel frcm nuclear radiation hazards.
53. Insure that required warning devices are incorporated in the commodity.
54. Provide for easy, simple, and rapid refueling, relubrication, and filling of all reservoirs and containers.
55. Provide for rapid inspection apertures on gearboxes, housings, and similar assemblies that will permit inspection, adjustment, or, when practical, repair or replacement of vital items inside of these housings, without the need for major disassembly. These apertures may be plugs, bailed hinged covers, windows or doors, requiring no tools to open or close, when possible or practical.
56. Provide quick disconnect devices for rapid removal and assembly of components.
57. Insure that a minimum of fasteners is used, and when feasible, that the fasteners can be operated rapidly, perferably without the use of tools.
58. Insure that all lubrication plugs and fittings are adequate and readily accessible on the completed commodity.
59. Insure that sufficient and readily accessible drains are properly located in compartments, tanks, reservoirs, and sumps.
60. Provide for rapid cleanability (post operation and inspection).
61. Insure that, to the maximum extent possible, maintenance on the commodity can be accomplished by personnel who are wearing arctic gloves and clothing in the open.
62. Insure that winterization requirements are incorporated.

TABLE 6-11. MAINTENANCE EVALUATION CHECKLIST (Cont'd)

GENERAL PRINCIPLES OF MAINTAINABILITY (Cont'd)

63. Insure that the provisions for kits are in the commodity and are adequate. This includes hardpoints, electrical, hydraulic, and mechanical connections or outlets, etc.
64. Insure that all labels are stenciled or are attached to the commodity or component, and that they will be legible after extensive use and abuse. This is particularly important for part numbers, component ratings, and types of fuels, lubricants, liquids, and gases.
65. Insure that lubrication charts, maintenance manuals, and operational manuals are either attached to the commodity or are readily available.
66. Insure that there are sufficient and adequate protection covers and attachments, securing devices, shipping and packaging tiedowns, seals, etc.
67. Insure that the design of the commodity is inherently self-packaging, whenever possible or practical. Self-packaging eliminates shipping crates, containers, etc., and permits ready reshipment without the need to replace the package.
68. Insure that instrument panels, particularly those for aircraft and vehicles, are hinged and/or readily removable as a unit for rapid servicing, testing, and calibration. Quick disconnects shall be provided.
69. Insure that all electronic gear is readily removable with quick-release fasteners and disconnects for rapid replacement, servicing, testing, and calibration. Each unit will be removable without disturbing any other component of the commodity.
70. Insure that component modularization design is used, as appropriate. Design modules to be repairable. (A module can be a throwaway item, in which case, it should not be made repairable.)
71. Insure that unitization design is used. (Unitization is the design feat of combining components of a system or function of a system into a removeable assembly.)
72. Insure that miniaturization design is used whenever suitable. (This feature reduces shipping, packaging, and transportation costs, and improves commodity and maintenance handling.)
73. Insure that commodity is designed for the minimum weight, taking into account reliability, durability, and maintenance freedom, example: do not design an item so light that it is constantly breaking or malfunctioning.
74. Consider advantages of modular replacement versus part repair versus throwaway design.
75. Provide for ballistic verification (telemetry; ordnance).
76. Provide easy and sure recognition of the malfunction to allow for rapid identification of the replacement action/repair required and thus reduce the complexity of the maintenance task.
77. Review areas of possible improvement since they affect the probability that the diagnosis of the malfunction and completion of the repair required may be corrected successfully within a specified time with available personnel resources.

TABLE 6-11. MAINTENANCE EVALUATION CHECKLIST (Cont'd)

GENERAL PRINCIPLES OF MAINTAINABILITY (Cont'd)

78. Establish minimum and maximum mean time between failure, mean time to repair, and downtime for the equipment/item and include in the maintenance engineering analysis data. If a like/similar item was previously fielded, review and analyze the failure rates associated therewith and, considering new technologies, attempt to improve maintenance in this area.
79. Review storage of vehicle basic issue item list and TA items to insure adequacy of storage facilities and technical manual coverage, as applicable.

ACCESSIBILITY CHECKLIST

1. Is adequate accessibility provided in all equipment and components requiring maintenance, inspection, removal, or replacement?
2. Is a transparent window or quick-opening metal cover used for visual inspection access?
3. Are access openings without covers used when this is not likely to degrade performance?
4. Is a hinged door used when physical access is required (instead of a cover plate held in place by screws or other fasteners)?
5. If lack of available space for opening the access prevents use of a hinged opening, is a cover plate with captive quick-opening fasteners used?
6. If a screw- fastened access plate is used, are no more than four screws used?
7. On hinged access doors, is the hinge placed on the bottom or is a prop provided so that the door will stay open without being held if unfastened in a normal installation?
8. Are items located so that other large items that are difficult to remove do not prevent access to them?
9. Are components placed so that there is sufficient space to use test probes and other required tools without difficulty?
10. Are units placed so that structural members do not prevent access to them?
11. Are components to which frequent access is required accessible without the removal of other components?
12. Is equipment designed so that it is not necessary to remove any assembly from a major component to troubleshoot that assembly?
13. Can screwdriver-operated controls be adjusted with the handle clear of any obstruction?
14. Are units laid out so that maintenance technicians are not required to retrace their movements during equipment checking?
15. Is enough access room provided for tasks that necessitate the insertion of two hands and two arms through the access?
16. If the maintenance technician must be able to see what he is doing inside the equipment, does the access provide enough room for the technician's hands or arms and still provide for adequate view of what he is to do?

TABLE 6-11. MAINTENANCE EVALUATION CHECKLIST (Cont'd)

ACCESSIBILITY CHECKLIST (Cont'd)

17. Are access doors made in whatever shape is necessary to permit passage of components and implements?
18. Are units removable from the installation along a reasonably shaped line?
19. Are heavy units (more than 25 lb) installed within normal reach of a technician for purposes of replacement?
20. Are provisions made for support of units while they are being removed or installed?
21. Are rests or stands provided on which units can be placed to prevent damage to delicate parts?
22. Are access points individually labeled so that they can be easily identified with nomenclature in the maintenance manuals?
23. Are accesses labeled to indicate what can be reached through this point (label on cover or close thereto)?
24. Are access openings free of sharp edges or projections that could injure the technician or snag clothing?
25. Are human strength limits considered in designing all devices that must be carried, lifted, pulled, pushed, and turned?
26. Are environmental factors (cold weather, darkness, etc.) considered in design and location of all manipulatable items of equipment?
27. Are units that are frequently pulled out of their installed positions mounted on roll-out racks, slides, or hinges?
28. Are easy overrides provided for limit stops for the replacement of racks and drawers?

IDENTIFICATION CHECKLIST

1. Are all units labeled, and, if possible, do labels show full identifying data?
2. Are parts stamped with information on relevant characteristics?
3. Are labels placed for full, unobstructed view?
4. On equipment using color coding, is meaning of colors given in manuals and on the equipment panels?
5. Is color coding consistent throughout system, equipment, and maintenance supports?
6. Are display labels of units imprinted, embossed, or attached in such a way they will not be lost, mutilated, or become otherwise unreadable?
7. Do labels and stencils pertaining to servicing or maintenance provide clear and specific instructions?
8. Does printed matter always appear upright to the operator or technician from his normal viewing position?
9. Do display labels on component covers provide relevant information concerning electrical, pneumatic, or hydraulic characteristics of the part?

TABLE 6-11. MAINTENANCE EVALUATION CHECKLIST (Cont'd)

IDENTIFICATION CHECKLIST (Cont'd)

10. Are display codes explicitly identified either in printed job instructions or directly on the panel, part, line, etc.?
11. Are displays and units labeled so that they correlate with notations appearing in system diagrams, technical manuals, or related literature?
12. Do display indications on storage spaces identify the various items to be stored therein?
13. Are lubrication points accessible and labeled properly?
14. Are labels used to indicate direction of movement of controls, especially when lack of such direction may result in damage to equipment?
15. When space permits, is each terminal labeled with the same code symbol as the wire attached to it?
16. Is each wire labeled with a unique designation?
17. Are life support equipment items explicitly identified and readily accessible?

INTERCHANGEABILITY CHECKLIST

1. Does functional interchangeability exist when physical interchangeability is possible?
2. Does complete interchangeability exist whenever practical?
3. Is sufficient information provided on identification plates and in related job instructions so that the user can judge adequately that two similar parts are interchangeable?
4. Are differences in size, shape, and mounting avoided when they do not reflect functional differences in the unit?
5. Is complete interchangeability provided for all items intended to be identical, interchangeable, or designed to serve the same function in different applications?
6. Are identical parts used whenever possible in similar equipment or series?
7. Are parts, fasteners, connectors, lines and cables, etc., standardized throughout the system, particularly from unit to unit within the subsystem?
8. Are cable harnesses designed so that they can be fabricated in a depot or factory and installed as a unit?
9. Is complete electrical and mechanical interchangeability provided on all like removable components?
10. Are bolts, screws, and other features the same size for all covers and cases on a given equipment?
11. Is interchangeability provided for components having high mortality?
12. When complete interchangeability is not practical, are parts or units designed for functional interchangeability, and are adapters provided to allow physical interchangeability, whenever practical?

TABLE 6-11. MAINTENANCE EVALUATION CHECKLIST (Cont'd)

SAFETY CHECKLIST

1. Are mechanical guards provided on all moving parts that could injure or entangle personnel?
2. Are edges of components and maintenance access openings rounded or protected by rubber, fiber, or plastic protectors to prevent personnel injury?
3. Are portable, hand-operated fire extinguishers provided where fire hazards exist or may be created, and are they of the correct type?
4. Are fire extinguishers placed so that they are readily accessible, but not immediately adjacent to points where fire probably would originate?
5. Are fault location systems designed so as to detect weak or failing parts before the emergency occurs?
6. Are jacking and hoisting points clearly, conspicuously, and unambiguously identified?
7. Are all hydraulic lines clearly labeled or coded to specific personnel or equipment hazard properties?
8. Do hatches have a positive lock for the open position and is the lock simple to operate and capable of withstanding all the rigorous requirements of field use?
9. Are struts and latches provided to secure hinged and sliding components against accidental movement that could cause injury to personnel during maintenance operations?
10. Do switches or controls that initiate hazardous operations require the prior operation of a related or locking control?
11. Are components located and mounted so that access may be achieved without danger to personnel from heat, sharp edges and points, and moving parts?
12. Are mechanical components that require the use of heavy springs designed so that the springs cannot be inadvertently dislodged and cause personnel injury or damage to component?
13. Do all charged units have less than 30 V appearing across capacitor or terminal after main power switch is turned off?
14. When technician may need to work on equipment with power on, is a "cheater" switch provided that automatically resets when access is closed?
15. Are appropriate warning signs provided at points of high voltages and sources of radiation?
16. Are propellant charges (when used) appropriately located, safed, and placarded to preclude inadvertent release?

TABLE 6-11. MAINTENANCE EVALUATION CHECKLIST (Cont'd)

SERVICING CHECKLIST

1. Are standard lubrication fittings used so that no special extensions or fittings are required?
2. Are standard lubricants that are already in the federal supply system specified?
3. Are adequate lubrication instructions provided that identify the frequency and type of lubricants required?
4. Are filler areas for combustible materials located away from sources of heat or sparking, and are spark-resistant filler caps and nozzles used on such equipment?
5. Are fluid replenishing points located so that there is little chance of spillage during servicing, especially on easily damaged equipment?
6. Are filler openings located where they are readily accessible and do not require special funnels?
7. Are fuel tank filler necks, flexible lines or cables, pipe runs, fragile components, and like items positioned so they are not likely to be used as convenient footholds or handholds, thereby sustaining damage?
8. When bleeds are required to remove entrapped air or gases from a fuel or hydraulic system, are they located in an easily operable and accessible position?
9. Are drains provided on all fluid tanks and systems, fluid-filled cases or pans, filter systems, float chambers, and other items designed or likely to contain fluid that would otherwise be difficult to remove?
10. Are drain fittings of few types and sizes used, and are they standardized according to application throughout the system?
11. When drain plugs are used, do they require only common hand tools for operation, and does the design insure adequate tool and work clearance for operation?
12. Are drain cocks or valves clearly labeled to indicate open and closed positions, and the direction of movement required to open?
13. Do drain cocks always close with clockwise motion and open with counterclockwise motion?
14. When drain cocks are closed, is the handle designed to be in the down position?
15. Are drain points placed so that fluid will not drain on the technician or on sensitive equipment?
16. Are drain points located at the lowest point when complete drainage is required or when separation of fluids is desired (as when water is drained out of fuel tanks)?
17. Are drain points located to permit fluid drainage directly into a waste container without the use of adapters or piping?
18. Are drain points placed where they are readily operable by the technician?
19. Are instruction plates provided, as necessary, to insure that the system is properly prepared prior to draining?
20. Are drain points located so that fuel or other combustible fluids cannot run down to or collect in starters, exhausts, or other hazardous areas?
21. Are lubrication requirements reduced as much as possible?

TABLE 6-11. MAINTENANCE EVALUATION CHECKLIST (Cont'd)

SERVICING CHECKLIST (Cont'd)

22. Are pressure fittings provided for the application of grease to bearings that are shielded from oil?
23. Are oil filler caps designed so that they:
    a. Snap and then remain open or closed?
    b. Provide large round opening for oil filling?
    c. Permit application of breather vents, dipsticks, and strainers?
    d. Are located external to enclosure, where possible, to eliminate necessity for access doors, plates, or hatches?

FASTENER CHECKLIST

1. Are fasteners for assemblies and subassemblies designed to operate with a maximum of one complete turn?
2. When tool-operated fasteners are required, are only those operable with standard tools used?
3. Are combination-head mounting bolts with deep internal slots and hexagonal heads used?
4. When high torque is required, are external hex-head bolts used?
5. Are mounting bolts, nuts, and screws designed to be semipermanentlg captive?
6. Is no more than one thread size per bolt size used in a given item of equipment?
7. Is mounting hardware unobstructed by nearby components or structural members?
8. Are assemblies and units designed to be replaceable by the use of standard tools?
9. Are guide pins on units and assemblies provided for alignment during mounting?
10. Are permanently attached tapped or riveted nuts used to avoid losing the nut or forcing the technician to hold the nut in place?
11. When tool-driven screws must be used, are types used that can be driven by several tools (screwdriver or wrench when possible. i.e., a hex head with screwdriver slot)?
12. Are access cover fasteners the captive type?
13. Are fasteners designed so that close torque tolerances are not required?
14. Are different types and sizes of fasteners held to a minimum?
15. Are fastener mounting holes large enough to allow "starting"?
16. Are fasteners made of rust-resistant material?
17. Are bolts mounted with heads up?
18. Are fasteners properly marked or coded?
19. Is maximum use made of quick-release fasteners?
20. Have clamps, fasteners, etc., been selected to permit fastening with one hand?
21. Is the shape of the screw head compatible with the thickness of panel?

TABLE 6-11. MAINTENANCE EVALUATION CHECKLIST (Cont'd)

FASTENER CHECKLIST (Cont'd)

22. If self-locking bolts (with fiber or plastic locking device) are used, is operating temperature below 250°F?
23. Is length of bolt or screw adequate?
24. Have small removable parts been secured by chains to prevent loss?
25. Are mounting structure and removable component studs and mounting openings properly positioned and aligned?

ELECTRONIC AND ELECTRICAL EQUIPMENT TEST POINT CHECKLIST

1. Is accessibility of external test points assured under use conditions?
2. Are test points grouped for accessibility and convenient sequential arrangement of testing?
3. Is each test point labeled with the name or symbol appropriate to that point?
4. Is each test point labeled with an in-tolerance signal or limits that should be measured?
5. Are test points labeled with the designation of the available output?
6. Are all test points color coded with distinctive colors?
7. Are test points provided in accordance with the system test plan?
8. Are test lead connectors used that require no more than a fraction of a turn to connect?
9. Are test points located close to the controls and displays with which they are associated?
10. Is the test point used in an adjustment procedure associated with only one'adjustment control?
11. Are means provided for an unambiguous signal indication at the test point when the associated control has been moved?
12. Are test points located so that the technician operating the associated controls can read the signal on display?
13. Are fan-out cables in junction boxes used for checking if standard test points are not provided?
14. Are test points coded or cross-referenced with the associated units to indicate locations of faulty circuits?
15. Are test points located near main access openings, in groups, properly labeled, and near primary surface to be observed from working position so as to reduce hunting time?
16. Do test points require test probe retention so that technician will not have to hold the probe?
17. Are built-in test features provided whenever standard portable test equipment cannot be used?
18. Are test points adequately protected, illuminated, and accessible?
19. Are routine test points provided that are available to the technician without removing the chassis from the cabinet?

TABLE 6-11. MAINTENANCE EVALUATION CHECKLIST (Cont'd)

ADJUSTMENT CHECKLIST

1. Are adjustments held to a minimum?
2. Will component selections hold their setting?
3. Can adjustments be accomplished without the use of special tools?
4. Can adjustments be accomplished without the use of special test equipment or techniques?
5. Can adjustments compensate for tolerance change?
6. Are adjustments and test points compatible?
7. Can installation or replacement of a factory-adjusted component be achieved without the requirement for readadjustment?
8. Can all required test equipment be attached without unbalancing any circuit?
9. Does the technical manual adequately explain adjustment procedures when the adjustments must be accomplished in a particular sequence?
10. Are items that are adjusted in a mandatory sequence appropriately placarded?

ELECTRICAL CONNECTORS CHECKLIST

1. If tools must be used to operate connectors, are only standard tools required?
2. Do connectors that are used for auxiliary equipment operate in a fraction of a turn or with quick snap action?
3. Are connectors that require no more than one full turn used to connect test equipment to a test point?
4. Can wires be unsoldered and removed without damaging lugs?
5. Are interlocks and automatic disconnects provided on all accesses to high-voltage areas?
6. Is each plug coded to an associate receptacle?
7. Are quick-disconnect plugs used when feasible?
8. When plugs must be safetywired, are provisions made for wiring?
9. Are systems designed so that receptacles are "hot" and plugs are "cold" when disconnected?
10. Are plugs and receptacles used for connecting cables to equipment units rather than "pigtailing" to terminal blocks?
11. Are field replaceable modules, parts, and subassemblies plug-in rather than soldered?
12. Are Connectors placed for easy accessibility for replacement or repair?
13. Are connectors designed to prevent accidental shorting of electrical contacts by external objects?
14. Are connectors placed to allow for a firm grasp for connecting and disconnecting?
15. Is each pin identified on each plug?
16. Are plugs so designed as to preclude insertion in the wrong receptacle?

TABLE 6-11. MAINTENANCE EVALUATION CHECKLIST (Cont'd)

ELECTRICAL CONNECTORS CHECKLIST (Cont'd)

17. Do connectors have aligning pins or keys that extend beyond the contact pins?
18. Are unkeyed symmetrical arrangements of aligning pins avoided?
19. Are plugs with self-locking safety catch used, rather than those that must be safetywired?
20. Are cables routed for technician accessibility when feasible, rather than under floorboards, behind panels, etc.?
21. Are cables routed so that they do not cross removable units or fasteners, or do not contact moving parts?
22. Are cables routed to preclude sharp bending to connect or disconnect?
23. Are cables, with connectors, provided with easy passage through walls, bulkheads, etc.?
24. Are connectors designed so that it is physically impossible to reverse connections or terminals in the same or adjacent circuits?

DISPLAYS AND CONTROLS CHECKLIST

1. Are all displays used in system checkout located so that they can be observed from one position?
2. On units having operator displays, are maintenance displays located behind an access door on the operator's panel?
3. On units without operator panel, are maintenance displays located on one face, accessible in normal installations?
4. Are all displays located for observation without removal or disassembly of any portion of the installation?
5. Are label displays provided to locate systems or components in the block diagrams?
6. Are circuits involving center null displays designed so that if power fails, the indicator will not reset in the in-tolerance position?
7. Are internal displays illuminated?
8. Are display scales limited only to that information needed to make decision or take some action?
9. Are moving-pointer, fixed-scale indicators used for adjustment procedures?
10. Are all-or-none type displays used when they will convey sufficient information?
11. Are numerical scales used only when quantitative data are required?
12. When some displays must provide numerical information and others only an in-tolerance or out-of-tolerance indication, are both types used?
13. Are scales used showing correct reading, preferably a center-scale colored area for in-tolerance indication?
14. Are related displays and controls placed on the same equipment face?
15. Is each display positioned to be read easily and accurately by the technician while adjusting its control?

TABLE 6-11. MAINTENANCE EVALUATION CHECKLIST (Cont'd)

DISPLAYS AND CONTROLS CHECKLIST (Cont'd)

16. Are display and control labels collocated so that the display label suggests which control affects which display?
17. When a wide range of display movement is required, are the associated controls such that a small movement of the control will yield a large display movement?
18. When fine adjustments are required, is the associated control such that a large movement of the control will yield a small display movement?
19. Are controls placed on panel in the order of normal use?
20. When controls are used in a fixed procedure, are they numbered in operation sequence?
21. Are all adjustment controls located on a single panel of the equipment or component in which the adjustments must be made?
22. Are controls located where they can be seen and operated without disassembly or removal of any part of installation?
23. Are front panel maintenance controls covered with access doors?
24. For concentric shaft vernier controls, are larger diameter controls used to refine adjustment?
25. Are knobs used for precision settings of 2-in. diameter minimum?
26. Are controls labeled with functional statement?
27. Are control position markings descriptive rather than coded or numbered?
28. Are control scales only fine enough to permit accurate setting?
29. Except for detents or selector switches, do controls operate with smooth, even resistance to movement?
30. Do selector switches exhibit sufficient spring loading to prevent being left between detents?
31. Do spring-loaded pushbuttons cause inconvenient finger pressure?
32. Are locking devices provided for maintenance controls that are subject to vibration or accidental movement?
33. Are controls so located to preclude inadvertent release or abuse?

REFERENCES

1. TM 38-710, *Integrated Logistic Support Implementation Guide for DoD Systems and Equipment,* March 1972.
2. DoD Dir. 5000.3, *Test and Evaluation,* 19 January 1973.
3. AR 70-10, *Research and Development Test and Evaluation During Development and Acquisition of Materiel,* July 1971. (Revised Draft dated 7 November 1973.)
4. FM 38-7, *Materiel Development Management,* November 1966.
5. AR 750-43, *Test, Measurement and Diagnostic Equipment (To Include Prognostic Equipment and Calibration Test/Measurement Equipment),* 3 March 1971.
6. MIL-HDBK-472, *Maintainability Prediction,* 24 May 1966.
7. AFSC DH 1-9, *Maintainability,* 20 December 1973.
8. MIL-STD-471A, *Maintainability Verification/Demonstration/Evaluation,* 27 March 1973.
9. Lawrence L. Lapin, *Statistics for Modern Business Decisions,* Harcourt Brace Jovanovich, Inc., New York City, 1973.
10. AMC Circular No. 715-13-74, *Procurement Instructions,* 22 October 1974.

BIBLIOGRAPHY

DA LOI, *Letter of Instructions (LOI) for Implementing the New Materiel Acquisition Guidelines,* 23 August 1972.

AR 1000-1, *Basic Policies for Systems Acquisition by the Department of the Army,* 30 June 1972.

CHAPTER 7
MAINTENANCE AND EQUIPMENT IMPROVEMENT

This chapter discusses the maintenance engineering and maintenance operations as basic activities of the materiel maintenance function. The maintenance functions—specifically the maintenance actions of inspection, preventive maintenance, and corrective maintenance—and the preparation, use, and disposition of maintenance records are addressed. The advantages and disadvantages of contract maintenance are described. In addition, the process of equipment improvement—including the identification, control, and implementation of improvements in the materiel—and an equipment modification program are described.

7-1 INTRODUCTION

Maintenance of materiel consists of any' action taken to retain materiel in a serviceable condition or restore it to serviceability. A weapon system, being a composite of individual materiel, is dependent in total on the availability or serviceability of its individual components. Unavailability of equipment results in the loss and/or degradation of combat/operational readiness of the system. The overall objective of materiel maintenance is to insure that Army materiel is sustained in a ready condition, consistent with economy, to fulfill its designed purpose. This objective is achieved by active participation of maintenance engineering in the overall development and design process. These activities consist of the following (Ref. 1):

a. Establishment of Maintenance Requirements. Initially, maintenance requirements are identified in the required operational capability documents. The requirements must be realistic and definitive enough to provide essential information required by the developing agency and all other agencies responsible for participating in the development and maintenance support of the item.

b. Program Reviews. Reviews, during the development phase, in which maintenance engineering activities participate assure that (1) maintenance specifications are being complied with, (2) maintenance-influencing design features (e.g., maintainability) are being incorporated to reduce maintenance task time and requirements for maintenance resources, and (3) maintenance resources are being properly identified through the maintenance engineering analysis process.

c. Planning Documentation. The maintenance support plan is prepared by the agency having logistic support responsibility for the new materiel. The plan includes operational requirements, the plan for maintenance, and user and support organizations. Also included are reliability and maintainability parameters, and decisions pertaining to repair levels, depot support, float requirements, support plans for the coordinated test program, a materiel physical teardown plan, mechanical and electronic packaging, and test and checkout.

d. Tests and Evaluation. Tests conducted during the materiel development are used to collect data to verify, in addition to performance, the maintenance aspects and suitability of the maintenance planning. These tests include engineering design, development, and operational tests. Coordination of the test effort encompasses the maintainability demonstration and maintenance evaluation. Each of these tests is used to provide assurance of the equipment maintainability and to demonstrate concurrently the adequacy of the maintenance organization, maintenance concept, training, publications, and maintenance support planned for the item tested.

e. Reporting System. The reporting system for fielded materiel provides the maintenance materiel management function with applicable data from which to base decisions on the planning, scheduling, and control of the materiel to insure equipment operational readiness. The system also provides the maintenance engineering function with the data from which maintenance requirements for new development items can be established, and/or equipment improvements for the developed materiel can be proposed.

Maintenance planning is guided by system support and equipment operational readiness objectives established by the Army and the Department of Defense, which are to:

a. Plan all life cycle support activities, in detail, early in the life cycle of equipment.

b. Design materiel for ease of maintenance.

c. Predict support requirements accurately.

d. Provide support costs.

e. Provide support and end items concurrently.

The following are basic principles of maintenance as announced by the Army (Ref. 1):

a. Each commander is responsible for the maintenance of equipment issued to his unit.

b. Maintenance will be performed in accordance with published maintenance doctrine at the lowest category consistent with the tactical situation and available time, skills, and tools.

c. Repairs will be accomplished on site whenever feasible.

d. Maintenance will be accomplished in accordance with the applicable Maintenance Allocation Chart (MAC), which assigns specific repair tasks to specific categories.

e. Unserviceable materiel beyond the maintenance authority or capability of an organization will be reported or evacuated promptly to the organization responsible for the next higher category of maintenance.

f. Unless precluded by the operational situation, all authorized maintenance within the capability of an organization will be accomplished before equipment is evacuated to the next higher category of maintenance. Higher categories will perform the maintenance functions of lower categories when directed by the appropriate commander.

g. Ordinarily, Table of Organization and Equipment units will not be designated to perform, as a primary mission, a combination of categories such as direct support and general support maintenance. Specific exceptions may be authorized by the Army for combining direct support and general support maintenance in special cases involving unit assignment, low-density equipment, complex weapon systems, and similar instances when justified.

h. Each unit will have an organizational maintenance capability to the greatest extent practicable, considering the size of the unit, its mission, economy of resources, and operational environment.

i. Table of Distribution and Allowances maintenance facilities at installations normally will be assigned combined direct and general support maintenance missions to provide maintenance support to units located or satellited thereon on a "repair and return to user" basis. These combined direct support and general support maintenance facilities also repair or overhaul unserviceable equipment for return to the local supply system.

j. Maintenance will be accomplished with due consideration to the economy of resources. The "inspect and repair only as necessary" principle will be applied at all categories of maintenance.

k. Continuous command emphasis on the prompt evacuation of repairable unserviceable components and end items to direct support, general support, and depot maintenance facilities is mandatory for timely maintenance contributions to materiel readiness. Depot overhaul programs are extremely sensitive to having precisely the planned number of unserviceable but repairable assets delivered at the planned time. When such delivery is not accomplished, depot overhaul cannot serve as a means of ready supply of major secondary items.

The increasing complexity and technical sophistication of Army materiel impose increasingly heavy demands on the Army's maintenance organization. These factors also tend to magnify the cost of materiel maintenance. Thus, increased emphasis and attention are being directed toward reducing the amount and frequency of required maintenance, the technical skills required to perform maintenance, and the amount of supply support required for Army materiel (Ref. 2). The maintenance engineer, through the results of maintenance engineering analysis, is provided with the basis for influencing or initiating equipment improvements throughout the materiel life cycle. It is of utmost importance that potential support/design interface problems be identified early in the development of equipment to avoid problems with deployed hardware and potentially costly modification or support programs. During the formulation of maintenance requirements, special considerations are given to the capability of the user. The feasibility of assigning a maintenance task to a maintenance level is influenced by the following factors: tactical concept for deployment; materiel technical factors; and peculiarity of the skills, tools, test equipment facility, and repair parts required. The maintainability and maintenance engineers, through close liaison, interchange maintainability analysis data and maintenance engineering analysis data during the maintenance concept formulation phase. The objectives of these two functions are assured through the cost trade-off process used to select the optimum maintenance concept. The basic approach to the cost analysis is to consider the cost of repair, the number of items to be repaired, the total logistic cost of supporting the equipment, and the cost of initial acquisition. Most cost. analysis involves a cost comparison of repair policies; e.g., equipment repair by component replacement at various maintenance levels, and repair versus discard-at-failure maintenance (Ref. 3).

The importance of the maintenance function must be understood and emphasized at all levels of maintenance. The importance of maintenance to combat effectiveness is not altered under either peacetime or limited emergency conditions. Readiness for combat always demands the same preparation and effort on the part of the entire maintenance system, with the possible added constraint of limited resources to do the maintenance job during limited emergency conditions (Ref. 1).Thus the maintenance requirements and support resources must encompass not only the actual materiel but must consider the requirement for field documentation to provide data for effective accountability, evaluation, and verification of the materiel maintenance function. This function includes the maintenance concept, supply procedures, facility requirements, user demands on the equipment in terms of personnel and environment, and other support resources. These field documentation data are used by the maintenance engineer to perform the maintenance engineering analysis, update the logistic support analysis data system, and initiate changes to the design or support resource, as required, to resolve any performance/support interface problems. Thus maintenance engineering, from the concept phase through deployment, performs a key function in the identification of maintenance resources and operations related to the materiel maintenance function.

7-2 MAINTENANCE FUNCTIONS

Maintenance functions are actions that must be accomplished on a system or system element in order to return a failed system or system element to readiness (corrective maintenance functions) or to insure continuous normal system readiness (preventive maintenance functions).

The major maintenance functions are listed on the maintenance allocation chart. These are inspect, test, service, adjust, align, Calibrate, install, replace, repair, overhaul, and rebuild. However, these are not the only functions with which maintenance engineering analysis must be concerned. Other functions—such as access, checkout, diagnosis, fault detection, and fault isolation—must be considered.

Another maintenance function that should be considered in the maintenance engineering analysis is cannibalization. Cannibalization is the authorized removal of serviceable or economically repairable modules and parts from unserviceable equipment by maintenance activities for use by those activities in the accomplishment of their maintenance and direct exchange functions, or to support local area/command supply systems. Normally, cannibalization of Army equipment is accomplished at the organizational, direct support, and general support levels of maintenance by the exchange of serviceable/unserviceable modules and parts between like items of unserviceable equipment, and the removal of serviceable or economically repairable modules and parts from locally disposable items of equipment prior to the release of these items to a property disposal officer. Cannibalization, however, usually is a "last resort" source for needed parts.

7-2.1 RECORD KEEPING (Ref. 4)

Army maintenance management procedures are based upon the concept of recording essential data concerning equipment operation and maintenance. The objective is to attain timely and adequate data required for the control, operation, and maintenance of materiel at each level of command, and at the same time insure that the quantity of data acquired is the minimum consistent with the objective. This paragraph identifies the type, preparation, use, and disposition of records used for recording the operational and logistic data used at the organizational and national levels. Intermediate commanders may establish additional data collection to facilitate management of their operational and logistic responsibilities.

7-2.1.1 Types of Records

Army maintenance management procedures require that the following types of records be maintained:

a. Operational Records. These records pertain to equipment utilization and dispatch control. They are maintained by all units, organizations, and activities responsible for the operation of self-propelled and towed vehicles, and stationary powered equipment.

b. Maintenance Records. These records pertain to the following materiel maintenance activities:

(1) Recording results of equipment inspections

(2) Recording results of diagnostic checkouts

(3) Scheduling and accomplishing preventive maintenance services

(4) Requesting maintenance support

(5) Recording maintenance actions

(6) Reporting equipment operational status

(7) Improving supply procedures within and between maintenance activities.

c. Equipment Historical Records. The equipment log is the historical record for a specific item of equipment. It is a control device for mandatory recording of events during the life cycle of equipment, including receipt, operation, condition, maintenance accomplished, modification, and transfer. The equipment log must be controlled and safeguarded against loss or damage. The log is identified permanently with the applicable equipment by nomenclature and registration or serial number. The most important use of the equipment log is to provide commanders with up-to-date information concerning the readiness of the item of equipment, the condition of equipment, and the identification of equipment requiring the greatest maintenance effort. The equipment log may be used as a control document for operational dispatch of equipment. When used for dispatch, the equipment log will be under the control of the operator or crew at all times.

d. Ammunition Records. These records pertain to the use, maintenance, and support of Army designed or produced:

(1) CBR ammunition materiel

(2) Conventional ammunition

(3) Class V items used on guided mis siles or rockets

(4) Special explosive ordnance disposa tools and equipment.

e. Calibration Records. These records are used to schedule, record, and report activities pertaining to calibration and maintenance calibration of materiel.

Close attention to recording the information accurately and completely is necessary. Although each record serves an individual purpose, one record is only a part of the system. A chain of information develops through the interrelation of each record to others in the system.

7-2.1.2 Use and Disposition of Maintenance Records

The following paragraphs concentrate on the maintenance records portion of the reporting system, briefly discussing the purpose, use, and disposition of some of the maintenance records:

a. Recording Results of Equipment Inspections and Diagnostic Checkout. The equipment inspection and maintenance worksheet record (DA Form 2404) is used for recording:

(1) Equipment faults (except for aircraft and parachutes) found during the operator's daily. inspection and service, periodic maintenance services, inspection of equipment by maintenance activities, diagnostic checkouts and spot check inspection of equipment

(2) The results of equipment serviceability criteria tests and checks prescribed by AR 135-8 and AR 220-1

(3) The results of a technical evaluation of a guided missile system

(4) The results of PMI-PMP checks of aircraft

(5) The results of technical inspections on all equipment to classify equipment prior to turn-in. Serviceability codes listed in AR 725-50 will be recorded.

The form is used by all personnel who perform inspections, maintenance services, diagnostic checkouts, equipment serviceability criteria (ESC) checks, and guided missile system technical evaluations. This is a temporary record and may be used to record the inspection of all components and attachments to a major item (e.g., a combat vehicle with radio and fire control equipment mounted, or a trailer-mounted generator), to record a complete day's inspection and servicing of a complete equipment system comprising several separate items of equipment, and to record the results of an inspection of several like items of equipment. The equipment inspection and maintenance worksheet record also is used for recording daily inspections and services (except aircraft daily inspections and administrative motor pools using automatic data processing cards for dispatching), periodic maintenance services, and inspection of equipment by maintenance activities as follows:

(1) When used by an equipment operator or crew for recording before, during, and after operation inspections and services: only those faults that cannot be corrected by the operator or crew, or that are corrected by replacing parts, will be recorded.

(2) When used by organizational maintenance personnel for recording periodic maintenance services: all faults found and corrective action taken as a result of the inspection will be entered.

(3) When used by support maintenance activities for performing initial and final inspections of equipment received for repair: all faults existing at the time of inspection will be recorded. This record, when used to complete initial inspections, will be attached to the maintenance request furnished the mechanic assigned to repair the equipment.

This record will be used for reporting equipment serviceability criteria tests and checks in conjunction with the technical manual prescribing the serviceability criteria applicable to the item of equipment concerned. This record also is used to report results of a technical evaluation of a guided missile system.

DA Form 2404,[1] used for recording the operator's or crew's daily inspection, will be furnished to the appropriate maintenance supervisor for action. When all corrected faults have been recorded on the appropriate form of the equipment log and all uncorrected faults have been transcribed to DA Form 2407[2] or DA Form 2408-14,[3] DA Form 2404 will be destroyed.

DA Form 2404, used to record a periodic service, will be destroyed when the following actions have been completed:

(1) Parts used have been posted to DA Form 2407.

(2) Uncorrected faults have been recorded on DA Form 2408-14 or DA Form 2407.

DA Form 2404, used for recording the performance of equipment serviceability criteria tests and checks, must be posted on DD Form 314[4] (except for aircraft) and will be retained by the using organization and maintained current until the next serviceability tests and checks are completed. Upon completion of the ESC tests and checks, DA Form 2404 will be reviewed by the maintenance supervisor, who will take all necessary actions required to improve the category rating. Any action not corrected immediately will be recorded on the equipment DA Form 2408-14. The ESC rating then will be posted on the equipment DD Form 314.

DA Form 2404, completed on items of equipment for which no permanent records are prescribed, will be destroyed after the correction of all listed faults or after the completion of the next prescribed periodic service, at which time remaining faults will be transcribed to the new DA Form 2404. When used for technical inspections, the form will be disposed of in accordance with appropriate supply directives.

DA Form 2404, used during aircraft intermediate and periodic inspections, will be appended to and filed with the applicable DA

[1] DA Form 2404 (Equipment Inspection and Maintenance Worksheet)

[2] DA Form 2407 (Maintenance Request)

[3] DA Form 2408-14 (Uncorrected Fault Record)

[4] DD Form 314 (Preventive Maintenance Schedule and Record)

Form 2408-13[1] when the following actions have been completed:

(1) The accomplishment of the specific inspection is recorded on the DA Form 2408-13 as completed.

(2) Uncorrected faults have been transcribed to DA Form 2408-13, DA Form 2408-14, and/or DA Form 2407, as applicable.

(3) All parts used have been recorded on DA Form 2407, DA Form 2408-16,[2] and DA Form 2410,[3] when applicable.

DA Form 2404, used for recording the performance of aircraft equipment serviceability criteria tests and checks, will be retained by the using organization until the next serviceability tests and checks are completed.

b. Scheduling Preventive Maintenance. The preventive maintenance schedule and record (DD Form 314) provides a means for recording scheduled and performed maintenance and lubrication services, and pertinent data required for readiness reporting. This record will be used for scheduling periodic maintenance services on equipment (except aircraft and parachutes) when the technical manual for the item of equipment specifies that the services are to be performed by a mechanic or operator under the supervision of maintenance personnel and for scheduling calibration services when DA Form 2416[4] is not used. It will be used for recording nonavailable time, not operationally ready, supply/not operationally ready, maintenance for organizational and support maintenance, and the results of current equipment serviceability criteria.

One record normally is initiated for each item of equipment; however, several like items may be scheduled on one record if they are scheduled for service on a common date. Maintenance services are scheduled at least one month or one service in advance, whichever time is greater.

When the information on a completed record has been transferred to a new record for continued scheduling of periodic preventive maintenance services, it may be destroyed. The current record will accompany the equipment on transfer or will be destroyed upon salvage of the equipment.

c. Recording Maintenance Accomplishments. The maintenance request (DA Form 2407) is used to request maintenance assistance and to record, report, and/or submit maintenance information. This record is used at all maintenance levels, as follows:

(1) At the organizational level, it is used for:

(a) Requesting maintenance support from supporting maintenance activities

(b) Reporting maintenance performed on selected items

(c) Reporting all maintenance performed on aircraft and specified components and on installed equipment, assemblies, etc.

(d) Reporting accomplishment of modification work orders

(e) Submission of equipment improvement recommendations

(f) Submission of warranty claim actions

(g) Reporting of "previously complied with" modification work orders

(h) Recording and reporting maintenance performed on specified tactical vehicles designated as administrative use motor vehicles and support equipment authorized to administrative motor pools

(i) Recording and reporting maintenance float equipment exchange actions.

(2) At direct/general support maintenance levels, it is used for:

(a) Recording all maintenance performed and all repair parts used, except common hardware and bulk materials

(b) Recording all maintenance performed on aircraft and specified components, and on installed equipment, assemblies, etc.

(c) Reporting the completion of modification work orders

(d) Submission of equipment improvement recommendations

(e) Submission of warranty claim actions

(f) Requesting repai'r of unserviceable components, assemblies, and subassemblies as a result of direct exchange (When

[1] **DA Form 2408-13 (Aircraft Inspection and Maintenance Record)**

[2] **DA Form 2408-16 (Aircraft Component Historical Record)**

[3] **DA Form 2410 (Component Removal and Repair/Overhaul)**

[4] **DA Form 2416 (Calibration Data)**

used in this manner, a multiple of the same stock number items may be placed on one maintenance request; i.e., 10 rifles, 5 starters, 30 carburetors, etc.)

(*g*) Requesting maintenance support of another maintenance unit support/activity (intershop maintenance request)

(*h*) Recording and reporting maintenance performed on tactical vehicles designated as administrative use motor vehicles and support equipment authorized administrative motor pools

(*i*) Reporting of "previously complied with" modification work orders

(*j*) Recording and reporting maintenance float transactions

(*k*) Recording and reporting maintenance actions for Department of the Army data sampling items.

(3) At depot maintenance level, it is used for:

(*a*) Reporting the application of all modification work orders

(*b*) Submission of equipment improvement recommendations

(*c*) Submission of warranty claim actions

(*d*) Recording and reporting all maintenance performed on aircraft and specified components and on installed equipment, assemblies, etc.

(*e*) Recording and reporting "on-site" maintenance performed by depot maintenance personnel

(*f*) Recording and reporting of "repair and return to user" maintenance performed at depots

(*g*) Reporting of "previously complied with" modification work orders

(*h*) Recording and reporting maintenance actions for Department of the Army data sampling items.

The record is used to report maintenance performed under contract, for reporting damaged or improper shipment of materiel, and for requesting and reporting maintenance on administrative use vehicles.

(4) The disposition of the record will be as prescribed below:

(*a*) The receipt copy is destroyed by the maintenance activity when equipment is returned to the owner.

(*b*) The National Maintenance Point copy is required for reporting to the national level only for aircraft, aircraft components, aircraft subsystems, maintenance float transactions, Department of the Army directed sampling items, and all modification work order applications. Such copies are forwarded in specified periods of time. Copies pertaining to equipment improvement recommendations and warranty claims are forwarded to addressees specified by TM 38-750. All other National Maintenance Point copies will be disposed of as prescribed by the local Commander.

(c) The control copy is forwarded as prescribed by the local command.

(*d*) The organization copy will be retained for a period of 90 days.

(*e*) The file copy will be retained by the maintenance activity for 90 days, except that copies pertaining to items in an approved sampling plan will be retained as specified in the plan.

d. Recording Equipment Operational Status. The materiel readiness report (DA Form **2406**) provides, for Department of the Army staff and commanders at all levels, information regarding the readiness status of equipment in the hands of using organizations.

The information contained in this report is designed to meet the following specific requirements:

(1) Provide commanders at lower levels with equipment status information for planning day-to-day operations.

(2) Provide installation and organization commanders with information on maintenance backlogs, serviceability of equipment, density of equipment, and availability of equipment for operation.

(3) Provide major commanders and intermediate commanders the materiel readiness status of equipment in the hands of using activities.

(4) Provide to the Department of the Army the materiel readiness status of designated items of equipment.

The materiel readiness report provides a standard procedure for reporting materiel readiness data. Procedures for its utilization are as follows:

(1) *Using Agencies.*

(a) The Department of the Army will use the report for collection of materiel readiness data on selected items of equipment.

(b) Commands below the Department of the Army level may use the report for collection of materiel readiness data on any additional items of equipment that may be required to insure operational readiness of the command.

(2) *Reporting Agencies.*

(a) All Army organizations or installations, including Reserve Components, maintaining a property book or a property account in accordance with established provisions in Army regulations will complete this report.

(b) The report may be maintained by organizations and activities on a day-to-day basis for the purpose of providing feeder data for periodic reports if desired locally.

The frequency of reports will be established based on the following:

(1) Accumulative reports will be prepared covering a 3-month period.

(2) An accumulative monthly materiel readiness report will be prepared covering a 1-month period for the first and second month of each reporting quarter.

(3) Commanders using the report for collection of equipment readiness data for other than Department of the Army level reporting purposes will prescribe the frequency for preparation and submission.

The types of equipment to be reported under the equipment operational status reports are:

(1) All equipments authorized or on hand, including all makes and models of materiel designated for reporting are reported.

(2) Equipment categorized as training aids or training equipment will not be reported.

(3) Service schools and training centers will not report those items of instruction equipment which meet all of the following criteria:

(a) Equipment is used in an approved plan of instruction.

(b) Equipment normally is not kept in a system configuration.

(c) Equipment is continuously disassembled and/or contains induced malfunctions (bugged).

e. Improving Supply Procedures Within and Between Maintenance Activities. Recording of the data on component removal, repair, and overhaul is accomplished by executing a component removal and repair/overhaul record (DA Form **2410**). This record provides a means of recording and reporting data required to control selected aircraft items, and selected missile components and parts (referred to as reportable items). Data recorded and reported on this record include but are not limited to identification and location of the item, current serviceability status, and the major item of equipment on which the reportable item is installed or from which it was removed.

This record is used to provide repair, control, and historical data for designated reportable items, whether installed or uninstalled. This record is initiated under the following conditions:

(1) When a reportable item initially is placed in the Army inventory, whether installed or uninstalled

(2) When a serviceable or an unserviceable reportable item is removed from an end item and is not reinstalled on the same item

(3) When a serviceable or an unserviceable reportable item is removed from a component or assembly and is not reinstalled on that item

(4) When the serviceability status of an uninstalled reportable item changes for any reason

(5) When the stock number of a reportable item is changed as a result of modification work order compliance

(6) When a reportable item is salvaged or otherwise becomes a loss to the Army's inventory

(7) When the record is prepared by a using organization for a reportable direct exchange (DX) item, copies will be delivered with the reportable item. If the DX activity is unable to furnish a serviceable replacement at time of delivery, one copy will be completed by the DX activity to provide a receipt for the using organization. The user will return the receipt copy to the DX activity when the required replacement item has been furnished.

The record is divided into four separate sections, which are used as follows:

(1) *Section I, Identification.* This section provides identification and usage data pertinent to the reportable item. Such identification and usage data are included on all copies of the form and are common to all subsequent actions concerning the reported item. Since the information in Section I must be on all copies of the form, personnel completing this section will inspect the carbon copies to insure legibility.

(2) *Section II, Removal Data.* This section identifies an end item or a component or assembly from which the reportable item was removed. This section also identifies the organization removing the reportable item, the reason for removal, circumstances under which the failure was detected, effect on the mission, and the organization to which the removed item was shipped.

(3) *Section III, Repair/Overhaul Data.* This section identifies the organization(s) performing checkouts, repair, and/or overhaul of the reportable item identified in Section I. It also provides a means of recording and reporting actions taken by each organization involved in the maintenance cycle, the man-hours required to complete such actions, and the disposition of the reportable item. The front sides of several of the copies of this record are identical to permit successive evacuations of the reportable items between maintenance activities without initiation of a new form. The reverse side of one of the copies provides for the entry and identification of parts used for repair or overhaul, as well as the entry of the applicable failure code.

(4) *Section IV, Installation Data.* This section identifies the end item or a component or assembly on which the reportable item is installed. It also identifies the organization making the installation, provides a means of reporting the man-hours required for installation of the reportable item, and provides usage data required for the preparation of other forms. In the event the reportable item is dropped from the Army inventory, this section also provides a means of reporting the reason for the loss.

Disposition of the copies of this record is as follows:

(1) One copy, upon task completion, will be disposed of in accordance with established procedures.

(2) One copy, upon completion of its use as a receipt, will be destroyed.

(3) Four copies will be processed, as applicable, to report succeeding actions affecting the item through the evacuation, repair, overhaul, installation, and/or loss cycle; e.g., one copy is completed by the direct support unit when that unit cannot repair the item, and one copy is completed by the general support unit when the item cannot be repaired at that level. In all cases, one copy is completed by the unit/activity completing the actual repair/overhaul action.

7-2.2 INSPECTION

Inspection, in its broadest sense, is the examination and testing of materiel and material to determine whether or not they conform to technical requirements. Inspection is accomplished at all levels of maintenance and during the acceptance of products from contractors and vendors. The discussion that follows will emphasize the inspection activities associated with deployed materiel. The principles advanced apply to other types of inspection.

The basic objectives of inspections accomplished on deployed materiel are to insure that the materiel is serviceable and/or to determine the requirement for actions that will enhance materiel serviceability. Inspections are conducted by operators and technicians as part of preventive maintenance programs. The inspections consist of visual observations, measurements, tests, etc., and specifically concentrate on predesignated areas that would indicate, by inspection, potential system problems. Commanders and supervisory personnel involved in maintenance management perform similar inspections with an added objective of instilling discipline into the maintenance system.

To attain maintenance economy and efficiency, it is important to achieve the objectives of inspections with the minimum feasible expenditure of maintenance resources. Consequently, inspections are accomplished in accordance with standards or procedures that provide specific guidance to inspectors. These standards are developed as a part of the maintenance engineering analysis process. Source data are contained in documents which suppliers of components, subassemblies, assemblies, etc., deliver with their products. Such documentation consists of technical and supply bulletins, operating manuals, maintenance manuals, drawings, etc. Maintenance engineering accepts or modifies the source data based on the application of the subassemblies, etc., in end items, the overall maintenance concept, service life, operational requirements, and historical data. In those cases where no supplier data are made available, engineering analysis is coupled with the foregoing considerations to determine inspection standards. After all inspection standards have been determined, they are integrated into an overall inspection program that requires minimum maintenance resources and has minimum adverse impact on system operational availability.

As a result of inspections or other evaluation activities, Commanders with subordinate units, or a unit Commander, may discover that a unit requires assistance in maintenance or maintenance related activities. This assistance will be provided upon request under the provisions of a Maintenance Assistance and Instruction Team Program (Ref. **11**). Under the program, technical assistance and expertise are furnished to unit Commanders to help them identify and solve problems that are contributing to the inability of their units to meet readiness standards.

The maintenance assistance and instruction team visits are not an inspection and do not result in adjectival ratings or scores. The purpose of the visits is to provide assistance and instruction in operation and management areas such as operator requirements, preventive maintenance and equipment repair, equipment condition and serviceability, unit readiness reporting, repair part and supply procedures, record and report management, and safety. The results of the visits are not disseminated outside of the visited unit.

7-2.3 PREVENTIVE MAINTENANCE

Increased materiel complexity, cost, and quantities have resulted in increased demands on Army maintenance resources. The requirement for quick response of the modern weapon system necessitates a maintenance program that provides the highest availability in the most economical manner. Effective maintenance management contributes to the readiness of materiel by improving the effectiveness and economy of planned maintenance operations. Such planned maintenance will provide the following benefits:

a. Increased system availability through minimizing unscheduled shutdowns due to equipment failures

b. Prolonged life of the equipment through minimizing harmful degradation/deterioration

c. Reduced maintenance costs through requiring fewer end item repair parts and skilled repair personnel.

The overall objective of materiel maintenance is to assure that Army materiel is sustained in a ready condition, consistent with economy, to fulfill its designed purpose.

7-2.3.1 Definition and Description

Preventive maintenance is defined as the care and servicing by personnel for the purpose of maintaining equipment and facilities in satisfactory operating condition by providing for systematic inspection, detection, and correction of incipient failures either before they occur or before they develop into major defects.

The elements of preventive maintenance, as applicable to any system, are as follows:

a. Servicing. Cleaning, preservation, charging, adding, painting, lubricating, etc., of materiel on a scheduled basis to prevent incipient failures.

b. Inspection. Periodic inspection of materiel to determine serviceability of materiel by comparing its physical, mechanical, and electrical characteristics with established standards.

c. Testing. Any test or checkout operation performed on a periodic or scheduled basis to determine serviceability and detect electrical or mechanical degradation.

d. Adjustment. To adjust, on a scheduled basis, specified variable elements of materiel to bring the system to optimum performance level.

e. Alignment. To change specified variable elements of an item to bring about optimum performance.

f. Calibration. Periodic determination of the value of characteristics of an item by comparison with a standard. Consists of the comparison of two instruments, one of which is a certified standard of known accuracy, to detect and adjust any discrepancy in the accuracy of the materiel being compared with the known standard.

g. Installation. To set up and use in an operational environment. As used in relation to preventive maintenance, it refers to those items which have a specified shelf life or which experience time cycle or wear degradation and must be replaced at specific intervals to maintain the required tolerance of the system.

The two types of maintenance that contribute to system downtime are corrective (unscheduled) and preventive (scheduled) maintenance. The elements of an efficient maintenance materiel program provide for the planning for and support of both types of actions. The objective of the unscheduled tasks is to restore the equipment to operational status with minimum degradation of its overall inherent reliability and with minimum impact on the materiel downtime. The objective of the scheduled tasks (preventive maintenance) is to prevent deterioration of the inherent design capability by performing scheduled actions that are planned to increase the service life of materiel and prevent accelerated materiel failure. Preventive maintenance is expressed in the quantitative terms of mean preventive maintenance time, median preventive maintenance time, and maximum preventive maintenance time. Preventive maintenance downtime is one element of the mean downtime used in the operational availability calculations (see par. 4-2).

7-2.3.2 Implementation

Preventive maintenance actions, established as requirements, must be accomplished on a periodic basis throughout the life cycle of materiel. The resources required to accomplish the actions are affected significantly by materiel design. The primary resource normally expended is manpower, and a significant number of man-hours is devoted to preventive maintenance during the average materiel life cycle. Maintenance engineering can use the cost of preventive maintenance man-hours and other resources to influence design through cost trade-offs. For the greatest probability of success, the effort must be accomplished early in the development phase, and reasonable design alternatives must be advanced. The first type of design features to be considered are those such as sealed bearings and self-adjusting components that eliminate preventive maintenance requirements. Next, all applicable maintainability features should be considered. Among these are features—such as accessibility and simplicity—that reduce time and skill requirements. Two other trade-off areas to consider are reliability and durability.

Preventive maintenance tasks are defined and allocated, together with the resources required to support them, during the maintenance evaluation phase of maintenance support planning. At this time, the frequency of scheduled preventive maintenance services is determined and the maintenance time standards are developed. The adequacy of the preventive maintenance service instructions is evaluated and the time standards are compared with actual times during the maintenance portion of the equipment service test. The tasks are those, such as servicing, inspection, adjustment, and calibration, which prolong system operation and useful life. These tasks normally are performed with minimum disassembly of materiel, and the system may be returned to operational status in minimum reaction time. Periodic tests may be conducted to verify system performance and insure that there are no leaks, loss of pressure, degradation of operational status, etc. Although preventive maintenance may result in system downtime during the performance of the preventive maintenance task, it will, in fact, reduce overall materiel downtime by increasing the service life and preventing failures requiring time-consuming corrective action. The consideration for preventive maintenance identification, task selection, and scheduling is an important factor in the materiel management by the commodity commands. Since system operational requirements (e.g., air defense system, aircraft, combat vehicles, etc.) may dictate extended operation, the design objective should be to develop materiel that may operate for extended periods of time without damage if preventive maintenance cannot be performed at the prescribed time.

An effective preventive maintenance program is one which schedules only those tasks necessary to meet stated objectives. The optimum schedule is one which does not increase maintenance costs without increasing materiel protection. In addition, in determining the appropriateness of preventive maintenance applicable to a given item or piece of equipment, two factors must be given prime consideration. These factors are its effect on system operational and availability requirements and its cost. Since preventive maintenance should not interfere with, or at least have minimal effect on, operations, it should be scheduled for slack or out-of-service periods, or should be performed when the equipment is down for other reasons. Insofar as possible, the scheduled preventive maintenance interval should be the same for all components of an assembly. Naturally, the cost of performing preventive maintenance on a piece of equipment, including the required resource cost, should not exceed the cost of corrective action.

The implementation of preventive maintenance is actually begun when the equipment is received either at the operation area for fixed sites or by the operating personnel for mobile field units. Upon receipt of the equipment, the scheduling function of the unit should incorporate the periodic maintenance requirements into the master schedule, and the maintenance personnel should perform the first increment of the maintenance. Performance of this maintenance should be in accordance with prescribed procedures to insure that the instructions are complete and accurate, and that all specified materials, tools, and test equipment are available and adequate to perform the task. Equipment not scheduled for use in the immediate future may be put into administrative storage, which is essentially a type of preservation with relaxed periodic preventive maintenance requirements. In some cases, duplicate items must be furnished for equipment that is essential to a continuously operating system, when the equipment must be removed from its operating area for preventive maintenance. This is known sometimes as a "changeout" operation.

Implementation of the preventive maintenance program is accomplished as prescribed in the technical manuals. The manuals contain the preventive maintenance procedures and schedules for the selected tasks. The manuals provide the documentation and sources of the criteria, and the user provides the implementation force. Assuming that the recommended preventive maintenance program reflects an optimum program considering the materiel, operation, usage, and user environments, the failure to implement the program by the user will result in degradation of the operational and service life of the materiel. If deviations from the scheduled program are not reported, reports may be analyzed improperly. This could result in changes to preventive maintenance schedules and tasks to correct equipment problems that may have resulted from improper implementation of the recommended schedule and not from an ineffective, planned maintenance program. Problems in scheduling, implementation, or changes to the scheduled program should be reported by the user, through the proper channels, for evaluation. Effective initiation, implementation, and reporting will insure optimum materiel maintenance management by the commodity commands.

7-2.3.3 Planning of the Preventive Maintenance Program

The planning of an effective, scheduled maintenance program consists of the identification, scheduling, and determination of tasks and facility requirements for the preventive maintenance actions. The steps involved in this planning effort are the following:

a. Compile data:

Obtain as much of the following data as possible.

(1) Engineering drawings
(2) Part list/repair part list
(3) Repair manuals

(4) Failure data

(5) Preventive maintenance tasks and frequencies presently required for present equipment

(6) Maintenance philosophy of equipment

(7) Operational environment.

b. Prepare a generation breakdown:

A generation breakdown is the classification of a system into incremental hardware levels. It entails breaking a system into subsystems, a subsystem into assemblies, the assemblies into subassemblies, and continuing down to the lowest hardware level, the piece part. The generation breakdown would be prepared by listing, from the system part list, all of the subsystems and parts called out on the engineering drawings. The engineering drawings of the subsystems would then be used to list each of its assemblies and parts. This process would be followed down to each piece part.

c. Determine mean time between failures for the items on the generation breakdown: Predict the frequency of failure for the item if preventive maintenance were not performed.

d. Determine the generation breakdown items that are repairable and/or replaceable: Use the maintenance philosophy to determine those items that are not to be repaired. If the nonrepairable items are assemblies, all of the parts will be considered nonrepairable and nonreplaceable. If the nonrepairable item is a replaceable item, its next higher assembly will be considered repairable.

e. Determine the criticality of all repairable/replaceable items to overall equipment operation: Without actual failure effect data, the criticality of an item to overall equipment operation must be based on engineering judgment and system analysis. Generally, those items that are not in a series path are not deemed critical. Those items that are not considered critical should be removed from consideration unless replacement cost is considered high.

f. Determine average operating cycle of the equipment per day: The operating cycle is the amount of time, in hours, that the equipment operates in one day. The average operating cycle $\bar{h}$ is determined by dividing the number of operating days into the total number of hours the equipment is predicted to be operating when placed in service.

$$\bar{h} = \frac{\sum_{i=1}^{d_t} h_i}{d_t} \tag{7-1}$$

where

$\bar{h}$ = average operating cycle per day expressed in hours per day

h_i = number of operating hours in day i

d_t = total number of operating days

For example, if the number of operating days is 280, and the total hours of operation is 2716 hr, the average operating cycle per day is

$$\bar{h} = \frac{2716}{280} = 9.7 \text{ hr/day}.$$

g. Determine, for each replaceable/repairable part, all of the possible preventive maintenance tasks that can be performed: From the basic preventive maintenance tasks, identify all possible tasks that may be applicable. This is accomplished by analyzing the equipment or its engineering drawings to determine the location of an item, its accessibility, its operating condition, etc. From this inspection, the tasks which possibly may be performed can be identified. After the tasks are identified, define the specific preventive maintenance actions that are to be performed. For example, if the general task of "clean" is determined to be applicable, the exact maintenance actions that entail the cleaning of the evaluated part must be stated; i.e., using alcohol and brush, remove all excess dirt from the chassis.

h. Determine possible causes of failure to the repairable/replaceable item: Without actual failure effect data, determination of failure causes must be based on analysis of the design and tolerance specifications of the item to predict what may cause a failure. Also, data from comparable items can be studied and applied to the item for prediction of the cause of failure.

i. Delete those preventive maintenance tasks that are not applicable to reducing predicted failure: Determine, from the cause of failures predicted in par. *h,* those tasks which do not eliminate or reduce those causes, and delete those tasks.

j. Determine the frequency of preventive maintenance tasks to reduce failures: A rule of thumb to determine initially the frequency of preventive maintenance tasks is to determine the mean time between failures *(MTBF)* and perform the identified preventive maintenance at one-half that interval. As a rule of thumb, *MTBF*/2 is chosen because it allows a tolerance for adjusting the part failure frequency to coincide with other part failure frequencies and facilitates preventive maintenance scheduling.

Example: If a bearing without preventive maintenance has an *MTBF* of 100 hr due to lack of lubrication, the lubrication frequency would be half of that, or 50 hr.

The *MTBF*/2 procedure is only a rule of thumb for a part. If an assembly is involved (assembly has two or more parts), and the assembly has failures due to a minimum of two parts, the frequency of preventive maintenance must be determined based on the *MTBF* of each part. As an example, consider a switch and motor assembly that has failures caused by the following:

(1) Switch contacts (dirt) – *MTBF* = 300 hr
(2) Bearing (burnout) – *MTBF* = 500 hr
(3) Brushes (wearout) – *MTBF* = 1600 hr

By using the *MTBF*/2 rule of thumb for each part, the following frequencies of preventive maintenance are obtained:

(1) Clean switch contacts every 150 hr.
(2) Lubricate bearing every 250 hr.
(3) Replace brushes every 800 hr.

These preventive maintenance tasks may be scheduled periodically by performing the tasks in the following manner:

(1) 150 hr – Clean switch contacts.

(2) 300 hr – Clean switch contacts; lubricate bearings.

(3) 450 hr – Clean switch contacts.

(4) 600 hr – Clean switch contacts; lubricate bearings.

(5) 750 hr – Clean switch contacts.

(6) 900 hr – Clean switch contacts; lubricate bearings and replace brushes.

k. Compare predicted preventive maintenance tasks and frequencies with the present preventive maintenance tasks and frequencies: The predicted preventive maintenance tasks and frequencies must be compared with the present preventive maintenance tasks and frequencies eventually to obtain the best preventive maintenance program for the equipment. The guidelines for adding preventive maintenance tasks and increasing frequencies are:

(1) All of the preventive maintenance tasks presently in a preventive maintenance program, if effective for similar materiel, and newly predicted preventive maintenance tasks should be included in the modified program.

(2) When preventive maintenance tasks are identical (present compared to predicted), the highest frequency of preventive maintenance should be used.

Without accurate data with which to analyze the predictions, the guidelines should be used to avoid inadvertent omission of necessary preventive maintenance tasks and frequencies. Unnecessary tasks and excessive frequencies can be eliminated subsequently when adequate data can be collected and applied.

l. Schedule recommended preventive maintenance and additions into the preventive maintenance program: General guidelines for scheduling the tasks are:

(1) During scheduled system shutdown for tasks that do not require excessive time.

(2) During nonoperational status for items that would require excessive system downtime.

(3) During equipment operation for tasks that are not hazardous and do not require system shutdown.

The tasks were combined so that the switch contacts (having the lowest *MTBF*) are cleaned every 150 hr, the bearing is lubricated every 300 hr, and the brushes are replaced every 900 hr, i.e., integer multiples of the shortest time.

m. Initiate data collection for accurate assessment of the preventive maintenance program: The data sufficient for assessing the effectiveness and economy of a preventive maintenance program and making indicated changes are, but are not limited to:

(1) Failure history of equipment:

(*a*) Total number of failures since equipment has been in operation

(*b*) Items that failed

(*c*) Date and time of each failure

(*d*) Cause of each failure

(*e*) How each failure was discovered

(*f*) Impact of each failure on system operation

(2) Equipment age:

(*a*) Daily operating time of equipment

(*b*) Accumulative total of equipment operating time

(*c*) Equipment installation date.

(3) Preventive maintenance history:

(*a*) Preventive maintenance tasks presently performed on equip. ment

(*b*) Frequency and schedule of each task presently performed

(*c*) Time to perform each task

(*d*) Pay per hour of personnel who performed each task

(*e*) Tools and test equipment used in tasks

(*f*) Materials consumed

(*g*) Items replaced.

(4) Corrective maintenance history:

(*a*) Repair times for each failure

(*b*) Date and time equipment was returned to operation

(*c*) Tools and test equipment used at each failure

(*d*) Materials used in corrective maintenance

(*e*) Parts replaced

(*f*) Pay per hour of personnel required to perform corrective maintenance for each failure.

(5) cost:

(*a*) Cost of materials consumed in preventive maintenance and corrective maintenance

(*b*) Cost of parts replaced during preventive maintenance

(*c*) Cost of repair parts during corrective maintenance

(*d*) Cost of tools and test equipment required for preventive maintenance

(*e*) Cost of tools and test equipment required for corrective maintenance

(*f*) Cost of labor for preventive maintenance

(*g*) Cost of labor for corrective maintenance.

Inspection is an important and prevalent element of preventive maintenance. Practically all of the elements of operational materiel are subjected to some degree of inspection at some time during their service life, and many are subject to periodic inspections to insure their serviceability. The inspections are conducted for one or more of the following conditions: deterioration, wear, damage, or completeness.

Complex systems, those with a diversity of equipment, and those which require frequent and varying preventive maintenance tasks require the use of a checklist to formalize and control the inspection process. The checklist provides a medium to insure that the recommended checks and services are performed and provides a source of data for evaluation of the preventive maintenance program. In principle, the checklist itemizes all of the points to be checked on any one piece or type of equipment. It is actually the primary control for inspection details and should indicate whether the condition of the equipment was satisfactory or unsatisfactory. If unsatisfactory, the specific condition and its cause should be described in detail, along with the action taken or recommended to correct it. For inspections to be effective, the completed checklists should be forwarded to a centralized agency for compilation into a cumulative inspection record and analysis. The analysis may indicate a need for a more comprehensive corrective action or an adjustment in the frequency of inspection.

A typical checklist for materiel preventive maintenance is contained in Table 7-1. The table is a tabulated listing of recommended organizational preventive maintenance checks and services the operator is to perform on a generator set. The item number reflects the recommended sequence for performing the tasks, and the references refer to the applicable lubrication orders (LO's) and technical manuals containing information related to the tasks.

Checklists may not be necessary to insure the accomplishment and control of preventive maintenance on systems with minimum preventive maintenance requirements. Logs or record books and technical manuals normally provide sufficient documentation on such systems.

7-2.4 CORRECTIVE MAINTENANCE

Corrective maintenance is defined as the remedial action performed, as the result of a failure or as the result of discrepancies found during preventive maintenance, to restore a system or an item to operational or serviceable condition.

Corrective maintenance is normally an unscheduled maintenance action, consisting basically of unpredictable maintenance requirements that cannot be preplanned or programmed on a specific time occurrence basis, but which requires prompt attention and must be added, integrated with, or substituted for previously scheduled workloads. This includes compliance with "immediate action" field changes, correction of discrepancies discovered during operation of equipment, and performance of repairs as a result of accidents or incidents. Work that necessitates special intermediate or depot level scheduling is also classed as unscheduled maintenance.

Downtime for a system is comprised of modification, delay, and maintenance time. Maintenance time consists of both preventive and corrective time. Corrective maintenance parameters are defined in terms of individual corrective maintenance task time, mean time to repair, median time to repair, and maximum time to repair. The corrective time, combined with the element of reliability; is a key factor in determination of the availability of the system (Ref. Chapter 4).

Basically, the time factor is a discrete measure of the maintainability of a system and includes the time for preparation, fault location, item obtainment, fault correction, adjustment and calibration, checkout time, and cleanup time. The task and time composition of a corrective maintenance action are depicted in Fig. 7-1.

The fundamental objectives of maintenance engineering are:

a. To insure that new materiel is designed for ease and economy of support.

b. To insure that an adequate economic support subsystem is provided in a timely manner.

The support afforded to the system is dependent on the maintenance resources available, but effective design and efficient planning provide for the optimum combination of the support/performance in terms of cost-effectiveness. Operational requirements of the system dictate the time requirement to perform the maintenance function, whether it be preventive or corrective maintenance. The maintenance engineering analysis is a means of reducing the downtime of the system by first providing a source for identifying and recommending design changes, and second, by providing the element by which adequate maintenance resources are identified to perform the maintenance functions.

7-2.4.1 Corrective Maintenance Flow (Ref. 6)

Fig. 7-2 is a maintenance flow diagram illustrating the five major sequential steps performed during maintenance. These steps are:

a. Recognition that a malfunction exists

b. Localization of the defect within the system to a particular equipment

c. Diagnosis within the equipment of a specific defective part or component

d. Repair or replacement of the faulty item

e. Checkout and return of the system to the service.

Repair is the correction of a malfunction by applying maintenance services to correct a

TABLE 7-1. PREVENTIVE MAINTENANCE CHECKS AND SERVICES (Ref. 5)

M— Monthly
Q—Quarterly

Item Number	Interval: Operator, Daily, B	Interval: Operator, Daily, D	Interval: Operator, Daily, A	Interval: Operator, W	Interval: Org., M	Interval: Org., Q	Item to be inspected	Procedure	References
1.		X					Oil level gage	Add oil as indicated by level gage.	LO.
2.		X					Flow indicator	Check flow indicator for condition of air cleaner element.	
2.						X		Clean or replace element if indicator shows above,service level and reset indicator.	
3.		X		X			Fuel filter	Tighten thumb nut if gasket is leaking. Clean weekly.	
4.	X						Fuel can	Add fuel as required.	TM 5-6115-450-15
4.						X		Inspect can and adapter for leaks and damage. Tighten loose mountings. Replace can or adapter if necessary.	
5.	X						Ground terminal	Check for proper ground.	
6.	X			X		X	Batteries	Tighten loose cables and mountings. Remove corrosion. Inspect for cracks and leaks. Fill to 3/8 in. above plates. Clean vent holes in filler cap before installing. Run engine weekly a minimum of 1 hr after adding water.	TM 5-6115-450-15
7.						X	Magneto	Replace pitted or burned magneto points. Adjust points. Check adjustment every 500 hr.	TM 5-2805-204-14
8.						X	Spark plugs	Replace spark plugs that have cracked insulator and burned electrodes. Clean and set spark plug gaps. Torque spark plugs.	TM 5-2805-204-14
9.						X	Generator	Clean dirt and obstructions from blower cover.	
10.		X				X	Instruments	Replace damaged instruments. Tighten loose mountings. With the unit operating, check for proper operation.	TM 5-6115-450-15

NOTE 1. OPERATIONAL TEST.
During operation observe for any unusual noise or vibration.

NOTE 2. ADJUSTMENTS.
Make all necessary adjustments during operational test.

NOTE 3. FIRE EXTINGUISHER.
Inspect for broken seal. Weigh the new and fully charged fire extinguisher and enter on inspection record.

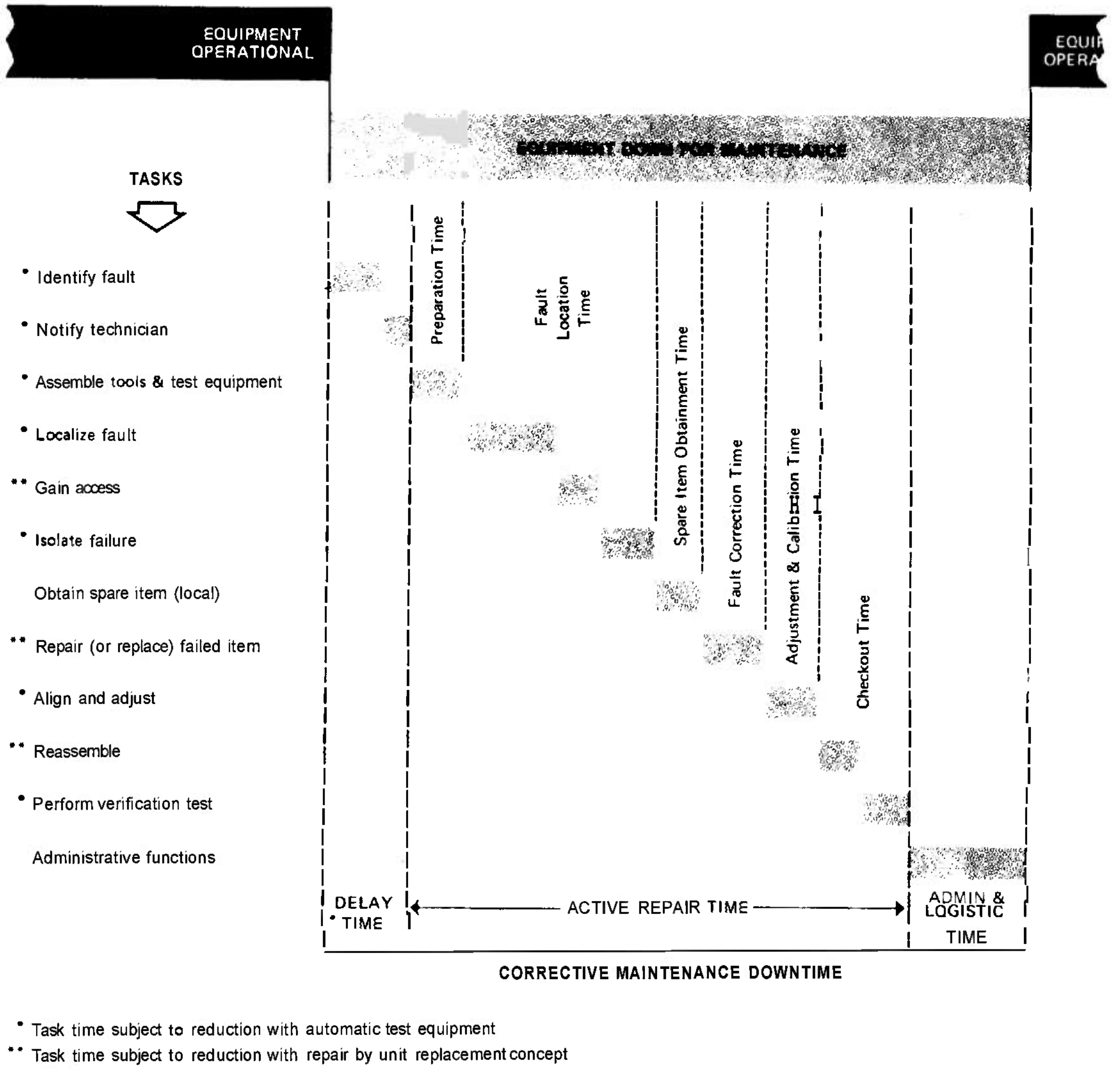


figure 7-1. Task and Time Composition of a Corrective Maintenance Action (Ref. 3)

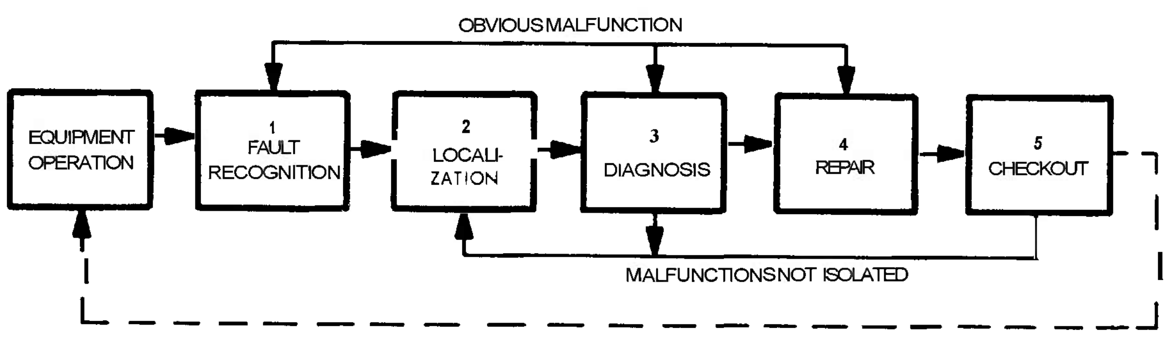


Figure 7-2. Maintenance Flow Diagram

specific fault in an item. Replacement involves the substitution of a serviceable like part, subassembly, etc., for an unserviceable counterpart. In some materiel, repair and replacement actions are followed immediately by alignment or calibration actions. Complementary to the maintenance steps are actions associated with assembly, disassembly, cleaning, lubrication, supply, and administrative activity.

Fig. **7-2** also illustrates two supplementary paths: one during which obvious malfunctions can be isolated immediately, the other for instances that require the technician to retrace his steps and perform additional analysis.

To expedite the actions in steps **1** through **3,** the use of automatic fault isolation is an effective tool, especially in the case of electronic equipment. In other cases, troubleshooting aids are used to help maintenance personnel in isolating the defective materiel. Table 7-2 is an example of a troubleshooting guide used for troubleshooting a generator set. The table delineates the malfunctions, probable causes, and corrective actions (including reference documentation). **A** more detailed type of troubleshooting flow diagram is shown in Fig. **4-5.**

7-2.4.2 Types of Corrective Maintenance (Ref. 7)

Corrective maintenance is not limited to the performance of the function only in the case of equipment failure as discussed in par. **7-2.4.1.** Other maintenance tasks which may be scheduled but also may be considered corrective maintenance actions are the functions of overhaul, rebuild, salvage, and servicing. These functions are defined as follows:

a. Overhaul. To restore an item to a completely serviceable condition as prescribed by maintenance serviceability standards, using the "inspect and repair only as necessary" technique.

b. Rebuild. To restore an item to a standard as nearly as possible to original or new condition in appearance, performance, and life expectancy. This is accomplished through complete disassembly, inspection of all parts and components, repair and replacement of worn and unserviceable elements (items) according to original manufacturing tolerances and specifications, and subsequent reassembly and test to original production requirements.

c. Salvage. As an element of corrective maintenance consists of disposing of materiel that is not repairable or usable and the utilizing of salvaged materiel, from equipment in itself not repairable, in the rebuild, overhaul, or repair programs.

d. Servicing. In relation to corrective maintenance, servicing may be required as a result of the corrective action performed. For example, engine repair may result in crankcase refill, welding on or adjacent to painted surfaces may result in a requirement to repaint, and air bottle replacement may require recharge of the system.

7-2.4.3 Corrective Maintenance Performance

The corrective maintenance action is performed in varying degrees at all maintenance organizations. Corrective maintenance at the organizational level normally is limited to system testing, fault isolation, and, usually, removal and replacement tasks of modular or plug-in units. Detailed repair of the removed items generally is assigned to a higher level of maintenance. As discussed in par. **7-2.4.1** the performance of corrective maintenance, especially at the organizational level, frequently is accomplished through fault recognition, localization, and diagnosis by automatic means. When these functions are performed manually, or the automatic procedure fails or is not considered feasible, detailed step-by-step procedures normally are provided the maintenance technician.

The prime consideration in the development and planning of the maintenance concept and maintenance support plan is to insure the following:

a. Minimum downtime of the system

b. Maximum operational availability

c. Supportability of the system with minimum impact on maintenance resources and life cycle cost.

Since corrective maintenance is an influencing factor for each one of these considerations, the design and support resources must reflect the optimum system configuration which reduces the corrective maintenance time and the demand on resources, and increases the operational availability of the system.

TABLE 7-2. TROUBLESHOOTING (Ref. 5)

Malfunction	Probable Cause	Corrective Action
1. Generator noisy	Mounting bolts loose	Tighten mounting bolts
2. Generator overheats	a. Generator overloaded b. Air passages blocked c. Ventilation inadequate	a. Reduce load b. Clean air passages c. Provide adequate ventilation
3. Generator fails to build up rated voltage	a. Residual field magnetism low b. Engine speed low	a. Flash field (par. 2-12)* b. Refer to TM 5-2805-204-14
4. Generator fails to supply power	a. Load cable defective b. Main circuit breaker defective	a. Repair or replace load cable b. Replace circuit breaker (par. 3-44)*
5. Generator voltage fluctuates	a. Generator overloaded b. Engine speed fluctuates	a. Reduce load b. Refer to TM 5-2805-204-14
6. Generator frequency drops under load	Engine lacks power	Refer to TM 5-2805-204-14
7. Generator voltage drops when load is applied or increased	a. Generator overloaded b. Engine speed	a. Reduce load b. Refer to TM 5-2805-204-14
8. Voltmeter indication too high or too low	a. Rheostat defective b. Voltmeter defective c. Engine speed incorrect d. Applied load not properly balanced across phases	a. Replace rheostat (par. 3-40)* b. Replace voltmeter (par. 3-37)* c. Refer to TM 5-2805-204-14 d. Distribute load properly
9. Voltmeter fails to register	a. Loose wire connections b. Voltmeter defective	a. Tighten connections b. Replace voltmeter (par. 3-37)*
10. Frequency meter fails to register	a. Loose wire connections b. Frequency meter defective	a. Tighten connections (par. 3-37)* b. Replace meter (par. 3-37)*

*TM 5-6115-450-15

7-2.5 EQUIPMENT MODIFICATIONS

Equipment alterations, particularly modifications, frequently generate a requirement for the expenditure of significant quantities of maintenance resources during a materiel life cycle. A maintenance engineering function is to assist in insuring that these resources are expended in a cost-effective manner.

7-2.5.1 Modifications

Within the Army, the term "alteration" is applied to any change made to materiel after the materiel has been entered into the Army inventory. A modification is described as an alteration that is permanent in nature and made on an item that is type classified as Standard (STD) or Limited Procurement (LP).

A standard item is an item/system of materiel which is determined to be acceptable for the mission intended and acceptable for introduction into the inventory. This designation includes items which have been or are being replaced by new STD items and which are still acceptable for the intended mission.

A limited procurement item is an item of materiel required for testing or other special use where a specified small quantity will be procured without further intent of additional procurement of the item under this classification. Each procurement under this classification will be justified and authorized separately. Items designated for limited procurement type classification are those which initially do not qualify for adoption as STD, but are required for one of the following purposes:

a. To meet urgent operational requirements which cannot be satisfied by a standard item

b. To test specified quantities of materiel prior to type classification STD

c. To maintain low rate initial production for a specified period of time

d. To maintain an established production line at the most economical or minimum sustaining rate during the period between final delivery of test models and the scheduled delivery of the first STD production model

e. Other special uses approved by HQDA.

Maintenance activities commonly referred to as retrofit, conversion, remanufacture, or design change are classified as modifications. Inline production changes, minor changes, and special-purpose equipment (winterization kits, fording kits, and ballistic antitank kits), which enable an item either to perform a specific mission or to meet a specific climatic or geographical condition, are not classified as modifications (Ref. 1).

Modifications should be limited to those that are necessary or will provide significant benefits for the costs incurred. Proposals for alterations that would result in marginal improvements or nonessential "nice to have" features should not be approved as modifications (Ref. 9).

Modifications are authorized by publication of a Department of Army Modification Work Order (MWO), or by appropriate instructions in a Depot Maintenance Work Requirement (DMWR) and contract work statements. The application of approved modifications is mandatory. The criteria for modification of equipment are:

a. Assure safety of personnel.

b. Prevent serious damage to equipment.

c. Eliminate risk of communication security or cryptologic compromise.

d. Insure compatibility with other interfacing equipment and its operator and maintenance personnel.

e. Significantly increase combat or operational effectiveness or significantly reduce requirements for logistic support.

Proposed modifications will be subjected to appropriate testing prior to consideration by the approving agency. This testing also will include the trial application of prototype modification kits prior to the publication of modification work orders (MWO's) or preparation of Depot Maintenance Work Requirements (DMWR's) and contract work statements authorizing the mass accomplishment of approved modifications.

MWO's will be prepared and published to authorize the accomplishment of all approved modifications except those which are to be applied only by a contractor or depot maintenance facility. Such modifications will be assigned MWO numbers, but will not be published as MWO's. Instead, the instructions for their accomplishment will be included in DMWR's or contract work statements, as appropriate.

Actions to rescind MWO's will be initiated by the responsible sponsoring agency when:

a. MWO accomplishment reports (DA Form **2407)** and other information/data sources indicate that the known densities of materiel in possession of using units and supply and maintenance activities at all levels, other than prepositioned stocks, have been modified. Modification kits will be obtained and retained by commands having prepositioned war reserve stock until such materiel has been modified.

b. Army materiel program changes indicate that continued accomplishment of an MWO is no longer justified.

c. It has been determined that an MWO is not accomplishing its purpose fully and will be superseded by another MWO.

d. The time compliance period has expired and there is adequate evidence that equipment is performing satisfactorily without the modification. In this case, the sponsoring agency is responsible for insuring compatibility of repair parts, publications, and training with all end item configurations in the field.

When an MWO is rescinded:

a. Modification kits will be removed from the supply system, and the responsible sponsoring agency will issue disposition instructions for the kits to the field.

b. Technical changes in the characteristics of materiel resulting from the MWO application and changes in repair part authorization occasioned by the MWO will have been incorporated in the applicable equipment manuals. This will constitute continuing authority for the retention of the equipment in its modified configuration (Ref. **9**).

7-2.5.1.1 Classification of Modifications (Ref. 9)

Modifications are classified as either URGENT, LIMITED URGENT, or NORMAL.

The classification URGENT is assigned to a modification when the condition it is intended to correct is such that the equipment must not be operated until the modification has been made. A modification is classified as LIMITED URGENT when the equipment may continue to be operated for a limited period of time—not to exceed **120** days—provided that specified cautions are observed. A modification is classified as NORMAL when it does not meet the requirements of URGENT or LIMITED URGENT. In the NORMAL classification, materiel is not rendered inoperable before the MWO is applied. In all cases, materiel in stock will not be issued until the modification has been applied.

7-2.5.1.2 €valuation of Modifications (Ref. 9)

The approval of a proposed modification is preceded and supported by a thorough evaluation of its total costs and impact on all affected functional areas. This evaluation is documented to include a stipulation of the primary criterion on which the proposal is based. To warrant approval of the proposed modification, this evaluation must demonstrate clearly that the need for the modification is fully justified, and the benefits to be derived override considerations of the costs to be incurred.

When the total costs of a proposed NORMAL modification exceed twice the annual costs of replacing or repairing materiel that becomes damaged because it has not been modified, the proposed modification is not approved.

The costs to be considered in computing the total costs of the proposed modification include those for the following:

a. Research, design engineering, development, testing, and procurement of modification kits

b. Application of the modification to eligible materiel

c. New parts, new or modified tools, and test, measurement, and diagnostic equipment

d. Revisions to publications

e. Inventory losses resulting from parts and modification kits to be made obsolete by proposed modification

f. Storage, transportation, training, and other applicable services.

The evaluation of proposed modifications include but are not limited to consideration of the following:

a. The criteria for modifications

b. The classification of modifications

c. An economic analysis conducted for proposed NORMAL modifications, which should identify funding requirements by budget program and fiscal year, and purpose

d. Man-hours required to accomplish the proposed modification. When the modification is to be applied by activities below depot level and the workload appears to exceed the capacity of a typical field activity to accomplish in addition to its normal maintenance mission, consideration will be given to accomplishing the modification by special teams, or providing other assistance from/by the proponent National Maintenance Point

e. Life expectancy, or the length of time the items to be modified are expected to remain in the inventory

f. Type classification of materiel to be modified

g. Support requirements: e.g., repair parts, special tools and test equipment, technical data and publications, and training and retraining needed to support the modified items

h. Lead time required to procure and test prototype modification kits, procure and distribute modification kits, and apply the proposed modification in relation to the remaining life expectancy of the materiel to be modified

i. Downtime, or the average time in days that the equipment to be modified will not be available due to the application of the proposed modification.

7-2.5.1.3 Development of Modifications

Maintenance engineering activities of sponsoring agencies direct the development of proposed modifications based upon analysis of equipment performance data and/or equipment improvement recommendations. They conduct required studies incident to the proposed modification of the equipment and prescribe the technical requirements for accomplishing the modification. Tools, test and handling equipment, publications, repair parts, etc., must be modified on a schedule that precludes degradation of maintenance support to the modified end items.

Modifications of any classification are developed for the following:

a. Materiel type classified as Standard or Limited Procurement

b. Materiel type classified as Contingency and Training when used exclusively for training

c. Materiel which assumes the type classification of the end item or assembly in which it is used

d. Accessory-type materiel not authorized to be type classified.

Modifications normally are not developed for nontype-classified materiel and for materiel with less than 3 yr remaining in its programmed service life. However, URGENT modifications may be developed for any materiel when the materiel is required for an operational mission and an improved replacement cannot be delivered within the required time period.

Modifications to be applied by direct support activities are developed to permit application, to the maximum extent practicable, by the replacement of easy-to-remove/install modules (component/assemblies). Modifications requiring the disassembly of modules and the replacement of interior piece parts normally are allocated for performance at general support or depot maintenance activities, or by special modification teams in field locations.

7-2.5.1.4 Quantitative Requirements (Ref. 9)

The responsible national inventory control point determines the quantities of kits, components, or parts required to be procured in support of the modification. The total quantitative requirements provide a base line for kit procurement, control, accomplishment, and follow-on support. The responsible commodity manager initiates procurement of modification kits, but procurement is not to be initiated until testing is completed and approved.

The development of kit quantities to support an economical one-time buy is developed in the cost study, with necessary updating based on the following: time interval between approval of modification and initiation of procurement action; solicitation and confirmation of total Department of the Army density of end items, assemblies, components, or parts requiring modification; and requirements for special tools, markings, and test equipment required for installation of the modification. Strict consideration must be given to washout factors, firing or operational schedules, stock position of serviceable and unserviceable assets, and rebuild requirements.

7-2.5.1.5 Application (Ref. 9)

As previously stated, MWO's may be applied by modification teams, depots, or support maintenance activities. Many factors enter into determining the activity that will apply the MWO. Among these are qualitative and quantitative skill, tool, test equipment, time, and cost requirements, and the classification of the modification. Normally, modification teams should be used for complex, time-consuming modifications that can be accomplished in the field, depots should be used for similar modifications that cannot be accomplished in the field, and support maintenance should be used for other modifications, since this is normally the most enonomical approach.

When a modification team is used, the National Maintenance Point will:

a. Furnish modification teams for application of MWO's and coordinate through command channels with the commands concerned to establish a mutually agreeable program for application of the modifications. This program will provide the following:

(1) A schedule for application

(2) Personnel and skills required

(3) Administrative support

(4) Logistic support

(5) Transportation requirements

(6) Tools and test, measurement, and diagnostic equipment

(7) Quantity, location, and availability of materiel to be modified

(8) Work facilities

(9) Exchange or rotation of assets

(10) Security (for materiel, personnel, etc.).

b. Insure that the modification teams are capable of accomplishing the following services, as required:

(1) Application of modification work orders to all serviceable and locally repairable unserviceable materiel

(2) Performance of operational checkouts of the modified materiel in accordance with the modification work order instructions

(3) Acceptance by the team chief of the modification (a commodity oriented Government inspector normally will accomplish this service), insure recording and initiation of modification work order application reports, and provide the supported command with such reports as may be required by that command.

c. Insure that all technical requirements are included or referenced in depot work instructions to support all materiel processed through depot maintenance.

When support maintenance is used to apply MWO's, the major Commander must insure that planning analogous to that described for the modification team program is accomplished. Availability of kits and technical documentation, the capability to operate and support two materiel configurations while the MWO is being applied, and the capability of the maintenance activity to accomplish normal maintenance and MWO maintenance without adversely affecting operational availability are among the factors that must be given careful consideration.

7-2.5.2 Other Alterations (Ref. 9)

a. Special Mission Alterations of Materiel Other Than Aircraft. Requests for approval of special mission alteration of materiel will be submitted through proper channels.

Such requests for the temporary alteration of other materiel will be submitted through channels to the major Army commander for approval, with an information copy furnished to the responsible AMC commodity manager.

Approved special mission alterations must comply with the requirements for safety of personnel and materiel.

Upon completion of the special mission, the original configuration of the materiel will be restored, if possible. Funding for alteration, support, and restoration will be the responsibility of the command which established the requirement for the alteration.

When a proposed special mission alteration of AMC managed materiel is considered to be permanent in nature, the approval authority will be the responsible AMC commodity manager, and the approval document will specify funding responsibilities for the alteration and disposition instructions for the item(s) modified following completion of the special mission.

b. Special-purpose Alteration of Materiel Other Than Aircraft. Alterations that have a limited application to meet climatic, geographic, or equipment interface conditions will not be identified or issued as a modification work order. Such special-purpose alterations usually are identified as winterization kits, tiedown kits, radio-TV frequency interference shielding, telemetry kits, and similar items, and are authorized in the equipment publications for the item. When authorized, these changes will be supported by the issue of parts or kits through normal supply channels. Instructions for application, operation, maintenance, removal, or disposition of these kits will be included in the equipment publications for the item.

c. Special Mission Alteration of Aircraft. Requests for temporary alteration of type classified Army aircraft to satisfy the requirement for a "one-time" special mission (excluding materiel tests) will be forwarded through command channels to the U S Army Aviation Systems Command (AVSCOM), for approval. Such requests will include description, drawings, and justification, and should be submitted so as to reach AVSCOM 180 days (if possible) prior to the date the reconfigured equipment is required. As a prerequisite to approval, an engineering analysis of the proposed change will be performed by AVSCOM to determine engineering feasibility of the proposed change and to preclude, adverse effects on equipment reliability or personnel safety. A positive "safety-of-flight certification" must be provided by AVSCOM upon accomplishment of approved alterations. Upon completion of the special mission, the user will advise AVSCOM of the estimated cost to return the materiel to its original standard configuration, if possible, and request guidance and disposition instructions. Funding for the total alteration (parts acquisition, installation, maintenance, removal, etc.) will be the responsibility of the requesting command.

d. Special-purpose Alteration of Aircraft. Normally, alterations that have a limited application to enable an item to meet some specific climatic or geographic condition will not be identified or issued as an MWO. However, when the design of a special-purpose alteration requires the incorporation of permanent provisions to facilitate the installation of special-purpose kit or equipment–e.g., the structure must be changed to accept armor plate, pods, or similar items–an MWO will be prepared to incorporate these provisions on the aircraft. When authorized, these changes will be supported by issue of parts or kits through normal supply channels. Instructions for application, removal, or disposition of such kits or materiel will be included in the applicable technical publications.

e. Minor Alterations. To qualify as a minor alteration, a proposed change must not:

(1) Require more than 2 man-hours to accomplish

(2) Require parts, assemblies, components, tools, fixtures, equipment, or skills beyond those authorized the category of maintenance performing the alteration

(3) Require mandatory reporting and recording except as a routine maintenance action (Exceptions require individual approval.j

(4) Cause rejection or rework of assets processed or being processed for delivery to U.S. Armed Forces or to foreign governments.

Such alterations may be authorized by the national level materiel manager concerned in the Equiprnent Improvement Report and Maintenance Digest Technical Bulletin and included in the applicable technical manual(s). Complete clarification and identification of change will be reflected in program work directives or supporting technical data provided to depots or contractors for the overhaul, rebuild, or remanufacture of the item or system concerned.

f. Recording and Reporting Special Mission, Special-purpose, and Minor Alterations. Minor alterations, special mission alterations, and special-purpose alterations will be recorded and reported as routine maintenance actions unless special reporting instructions are included in the document or equipment publication which authorizes the alteration.

7-3 CONTRACT MAINTENANCE (Refs. 1 and 9)

Contract maintenance is the maintenance performed under contract by commercial organizations on a one-time or continuing basis without distinction as to the category of maintenance. The types of maintenance include modification, modernization, rebuild, overhaul, repair, or servicing of materiel. Contract maintenance provides an effective means for augmenting the resources of the Army in accomplishing its maintenance mission. Its principal applications are in the following areas:

a. For the accomplishment of depot maintenance requirements that exceed the military capability and capacity retained to support mission essential materiel when such requirements can be satisfied in a cost-effective manner.

b. For the accomplishment of organizational, direct support, general support, and depot maintenance requirements in support of commercial equipment and nontactical (e.g., administrative) elements when military control and performance of such work are not required for military effectiveness, personnel training, or rotation and career development of Army personnel.

c. For the temporary performance of organizational, direct, and general support maintenance of materiel pending the attainment of an organic capability or to accommodate peak workloads of a transitory nature.

d. When required for an interim period to attain an earlier operational status for new military materiel.

e. For accomplishment of analytical overhaul or modification of new military materiel entering the inventory, or when the extent or complexity of the modification or modernization work to be accomplished requires the technical qualifications of the original manufacturer of the materiel.

7-3.1 CONTRACT MAINTENANCE PHASES

Contract maintenance consists of two phases. The first phase is that maintenance provided by the development contractor during the predeployment or preissue period, when the materiel is undergoing the development/operational tests. Some degree of recycling of equipment usually results from these activities. It is essential, during the first phase, that any requirement for contract maintenance be clearly set forth in the development Request for Proposal.

In the second phase, contract maintenance must be planned for all nonmission essential items requiring depot maintenance. Maintenance of mission essential items generally is authorized only for in-house (Army) depot maintenance. As previously noted, the second phase of contract maintenance follows the issue of equipment and also may be used in lieu of or in augmentation of Army depot maintenance. In this second phase, contract maintenance provides an alternate means, at the disposal of the support manager, for augmenting the existing maintenance capability. The second phase of contract maintenance also includes the maintenance, rebuild, overhaul, repair, modification, modernization, or servicing of equipment or materiel, performed under contract by the original manufacturers, or by commercial contractors, on a one-time or continuing basis. It provides a supplementary capability for maintenance of military and commercial types of materiel, when the workload requires manhours beyond those available at Government facilities, or when no Government facilities are available in the vicinity of the end items to be overhauled. Services may be performed by commercial organizations, including the original manufacturers, without distinction as to the level of maintenance.

7-3.2 ADVANTAGES AND DISADVANTAGES

Contract maintenance may be used for either new or used equipment. When properly used, it provides multiple advantages such as:

a. Releasing military maintenance capability and facilities for more essential work

b. Reducing the requirement for investment in facilities, equipment, and training of maintenance personnel

c. Providing flexibility in maintenance programs

d. Resulting in new benefits to the Government without compromising basic military mission requirements

e. Augmenting depot overhaul programs beyond available skills and facilities.

Some disadvantages are associated with contract maintenance. The principal disadvantages are:

a. Its use could prevent the timely attainment of the required military maintenance capability.

b. It could result in uneconomical use of existing facilities which, because of other requirements, must be retained.

c. Under exceptional circumstances, unacceptable security risks could be incurred by its use.

7-3.3 DECISIONS

Contract maintenance must be planned and executed carefully if it is to provide the Government with the greatest net cost benefits without compromising basic military mission requirements. The decision to use contract maintenance should be made only after carefully considering information furnished by support development personnel who are assigned to the development project. Some factors to be considered should include but need not be limited to:

a. The economics involved

b. Workload involved

c. Availability of test, measurement, and diagnostic equipment, if required, in Government direct support units, general support units, or depots *d.* Personnel and skills available

e. Tables of organization and equipment units which will use the equipment

f. Level of maintenance required to repair the equipment

g. Requirement for spare tools (availability of tools)

h. Quantity of end items procured

i. Modification programs which cause an increased workload

j. Impact on military organic capability for support of mission essential equipment.

Another facet of the contract maintenance decision concerns the required intensity of depot contract maintenance. The support developer considers the minimum required effort for support of the depot mission and develops or retains only that depot level maintenance capability which is essential. Materiel that will require continuing depot level contract maintenance to sustain operations under emergency or wartime conditions, in addition to insuring operational readiness during peacetime, is also evaluated. Depot maintenance shop facilities that should be developed or retained as part of contract maintenance must be adequate to meet emergency or wartime requirements when used on a multishift basis (up to 120 hr per week). The minimum peacetime capability to be retained is determined by the establishment of a level of manning effort to use the retained shop capacity on a single-shift (40 hr per week) basis.

The part the Government will play in contract maintenance is also an important facet of the contract maintenance decision. Information developed during the various phases will aid the support developer in determining whether he will use Government resources or negotiate a maintenance contract. Prior to the awarding of any contract, a pre-award survey must be made to determine if the contractor has the proper tools, facilities, skills, and test and calibration equipment to perform the services required. The Government may, upon the basis of certain conditions, furnish repair parts, components, and assemblies, or it may require the contractor to furnish all necessary supplies and support for the overhaul of the items or systems. It may be desirable to require the contractor to furnish technical assistance to the field. This would depend upon the ability of the Government to supply trained technicians or engineers when required.

Although the contract maintenance decision usually is concerned with depot level activities, it also has application to the accomplishment of organizational maintenance for Army in-the-field using activities. When used for this purpose, it normally will be accomplished at the equipment operating site, under military control, and used to augment, not replace, military capability.

7-3.4 SPECIFICATIONS, REQUIREMENTS, AND DATA

Once the decision has been reached to use contract maintenance, it is necessary to develop work statements and specifications for contractor guidance. Contracts for maintenance support should incorporate, by reference, necessary work specifications to insure that the support requested is provided in an effective and efficient manner. These specifications should be prepared by maintenance functional, not procurement or contracting officer, personnel.

Work statements and specifications should be developed in a manner that will provide maximum latitude. to prospective contractors in determining the mix of labor and materiel, including Government furnished materiel, they will need to produce a quality product at the least total cost to the Government.

Work statements should require that the support contracted for be provided in measurable end items; i.e., specific products or maintenance services, not just labor expressed in man-hours or personnel equivalents.

Work specifications included in maintenance contracts should include a specific time frame or production schedule within which the contractor will be required to accomplish the work.

In addition to the preceding general requirements, the following specific information and data should be furnished the contracting officer:

a. Specific identification and location of equipment and/or items to be processed *b.* Quantitative input and output schedules and priorities for accomplishment of the workload(s)

c. Specific technical instructions for the work to be accomplished. (When applicable, technical instructions for preservation and packing of processed equipment and/or items for shipment should be included.)

d. Inspection and test procedures and output standards for completed work

e. A repair part list associated with the equipment or item(s) to be overhauled or repaired. (Such lists will include repair part replacement factor data, when available, and itemized standard pricing information.)

f. Special instructions for part rework and/or component repair or replacement when applicable

g. Disposition instructions for repairable parts and/or components

h. Management information reporting requirements, including frequency intervals

i. Tentative disposition schedule of completed equipment and/or items

j. The proper financing appropriation, appropriate budget program, and applicable activity account to which all elements of cost will be charged.

Finally, cost forecasts should be developed and included with all equipment maintenance work requirements submitted to contracting officers for accomplishment by contract. These forecasts should be based on the most recent costs actually incurred in the accomplishment of like or similar work either by organic or contract sources. They should include elements such as:

a. Total labor and materiel (Government- and contractor-furnished) cost

b. All appropriate overhead and administrative expenses

c. Any other appropriate costs.

7-3.5 CONTRACT MAINTENANCE USAGE

The following are typical examples of proper contract maintenance usage:

a. Real Property Installed Equipment. This equipment usually is associated with fixed installations and includes equipment such as motor generator sets, furnaces, air conditioners, and power distribution equipment. Generally, these are commercially designed items and, in many cases, are one of a kind. Local commercial repair shops and vendors are available to repair equipment failures that are beyond the capability of base maintenance operations.

b. Tactical Deployed Equipment. Complex, high-performance missile and ground equipment, such as that used by a field artillery battalion, requires considerable modification to keep the system current with the state of the art. In many cases, the hardware is deployed outside CONUS and it is uneconomical to return the equipment to a depot for modification installation. In this case, a contract for modification services with the development contractor definitely would be in the Government's best interest.

c. Contractor Special Manufacturing Techniques. There are occasions when the Army Depot simply cannot duplicate the original manufacturer's process. This is especially true in those areas generally regarded as high technology. This is true even though the Government has purchased full-range documentation as a part of the development or production contracts. In this case, contract maintenance is much more logical and cost effective than attempting to establish an organic capability within the Army Depot system, especially in the case of equipment with low inventory density.

7-3.6 PLANNING

Planning for contract maintenance must encompass the conceptual, validation, full-scale development, and production and deployment phases. When used, contract maintenance support should be planned and used in a manner which will provide maximum effectiveness under emergency or wartime conditions, particularly when the contract involved is **a** long-term or continuing type.

If used for the support of new equipment, contract maintenance should be planned well in advance of the introduction of the equipment into the operational inventory. This is necessary in order to obtain the required tools, test, measurement, and diagnostic equipment, repair parts, facilities, and qualified personnel.

When contract maintenance support is being planned for equipment already in the inventory, provisions also should be made for necessary procurement lead time. The entire contract technical requirement package should be furnished the contracting officer in sufficient time before the desired date for the start of work to allow for timely completion of the full procurement cycle in accordance with normal commercial practices. This cycle includes contract preparation, advertising, and solicitation, receipt of bids and evaluation of prospective contractors, award of the contract, and advance preparation time for the contractor selected.

In general, the conceptual phase contract maintenance plan should define the requirements for and schedule the accomplishment of contract maintenance support of the system equipment, including support equipment. It provides for contractor support of all appropriate tests, such as development/operational tests in the preoperational period, and provides for appropriate depot level support in the operational phase.

In response to the Government RFP, the contractor should be required to prepare a plan for a contract maintenance program based on work statements selected by the support developer. Unless otherwise specified, the contractor should plan to terminate contract maintenance support below depot category of maintenance when materiel is introduced into the Army inventory.

The contractor's plan should contain the following:

a. Requirements for contract maintenance support of materiel being developed (Planning information should substantiate these requirements.)

b. Procedures for initiation and termination of contract maintenance to Army support

c. Determination of resources (facilities, tooling, support equipment, repair parts, Government furnished equipment, personnel, etc.) required for contract maintenance

d. Documentation of contract maintenance procedures, requirements, and data.

The contractor should:

(1) Maintain historical records covering every item which has a significant bearing on the performance, life, or maintenance requirements of the materiel being developed.

(2) Establish maintenance and repair procedures and repair part supply to support the scheduled and unscheduled maintenance of the materiel for which the contractor is contractually committed.

(3) Establish a system for the analysis of work in progress, and revisions of requirements to attain a more efficient support effort.

(4) Prepare reports of all failures affecting operation or maintenance, including time to repair and the maintenance man-hours, and forward them through maintenance engineering for processing.

(5) Forward repair parts usage data to maintenance engineering for preparation of the final provisioning documentation.

(6) Forward reports of errors in technical publications for review and correction.

e. Substantiate and document the results of cost-effectiveness studies and trade-off analyses conducted relative to contract maintenance requirements.

7-3.7 IMPLEMENTATION AND ASSESSMENT

Prior to entering full-scale development, the contractor should be required to revise the plan in accordance with additions or deletions of work statements as specified by the support developer and in accordance with the changes negotiated in the development contract. Upon approval of the revised plan by the Government, the plan should become the basis for the contractor's contract maintenance program. The contractor should be required to implement the Government approved contract maintenance plan, and should update this plan throughout the contract effort when necessary.

The contractor also should update the contract maintenance plan prior to entering the production phase. These revisions should be in accordance with additions or deletions of work statements as specified by the support developer. Upon approval of the revised plan by the Government and award of contract, the plan should become the basis for the contractor's contract maintenance program.

The contractor should be required to:

a. Implement the Government-approved contract maintenance plan, and should update this plan throughout the contract effort when necessary.

b. Provide for accomplishment of the necessary operations and maintenance transition tasks prior to turnover of maintenance operations to the Army. Normally, except at the depot level of maintenance, turnover will occur at the time of initial delivery of equipment of tactical units. As a minimum, the contractor should certify that:

(1) Maintenance of the equipment has been accomplished, and such service has been recorded in appropriate equipment logs.

(2) Reports or data related to the transition have been submitted to the proper authorities.

(3) Followup technical assistance recommendations have been made as appropriate.

(4) Item accountability determinations and reports have been accomplished as required.

Contract maintenance must be monitored carefully. Maintenance workloads accomplished by contract should be given the same emphasis and level of management attention as workloads performed by organic activities. Production, accrued cost, and other management information should be obtained and used by Army materiel management activities to measure the progress and efficiency of contractor performance, determine and maintain cognizance of costs incurred by the contractor to assure that they do not exceed established parameters, assure that Government-furnished equipment is used and/or properly accounted for, and initiate required management action to resolve problems and correct unsatisfactory situations.

Information and reports that are useful for the monitoring process are generated when maintenance is performed under contract. The scope of these data may be expanded to meet needs for complex systems and equipment configurations. The following types of reports and information (generated when maintenance is performed under contract) are examples of those prepared and detailed as specified by the requiring agency.

(1) Maintenance log

(2) Work-in-progress report

(3) Maintenance support assets

(4) Time schedules

(5) Report of turnover from contractor maintenance to Government maintenance

(6) Selected failure reports

(7) Individual data items, as required, which are listed by the activity on the contract data requirement list as separate line items.

This information and data can provide considerable management visibility into the contract maintenance operation; for instance:

a. The maintenance log provides a basic evaluation and an analysis of the life, performance, and maintenance requirements of Army equipment and materiel installed and operated by the contractor.

b. The work-in-progress report covers at least the following areas of continuing activity:

(1) Status of contractor facilities

(2) Problems which may be anticipated

(3) End item performance following completion of tests

(4) Types of tests performed

(5) Number of contract maintenance personnel on site

(6) Training to accomplish the mission.

c. The maintenance support asset report normally is furnished as requested and scheduled in the contract.

d. Time schedules include maintenance support activities. Some of these considerations are:

(1) The amount of projected equipment for which downtime is indicated

(2) The schedule for daily, weekly, monthly, and quarterly inspections

(3) Inspection, testing, and calibration of maintenance support assets

(4) Training of Government personnel

(5) Accomplishment of authorized equipment modifications.

e. The report of turnover from contractor maintenance to Government maintenance covers the accomplishment of all transitional and maintenance tasks.

f. Selected failure reports cover failures beyond those that are anticipated and corrected as normal routine.

7-3.8 MAINTENANCE ENGINEERING INFLUENCE

The maintenance engineering discipline can have considerable impact on the successful application and implementation of contract maintenance. Maintenance engineering analyses during the conceptual, validation, full-scale development, and production phases determine maintenance requirements. These requirements include skills, facilities, tools, support equipment, etc. Trade-offs among such considerations as leadtimes, cost, and total resources available will establish criteria for measuring the benefits of contract maintenance support.

7-4 EQUIPMENT IMPROVEMENT (Ref. 11)

Prior to expanding on the methods and techniques of effecting equipment improvements, it may be beneficial to discuss the subtle differences between the terms "equipment modifications" and "equipment improvements".

Equipment modifications are any permanent alterations made to materiel that has been accepted into the Army inventory and subsequently type classified as Standard or Limited Procurement (see par. 7-2.5.1). The meaning of equipment modification is thus restricted to the physical act of changing certain types of fielded hardware.

In contrast, equipment improvements are those changes to the design, manufacturing process, materials, handling processes, or technical directives which will enable an item to meet or exceed the specified mission objectives. Those equipment improvements which meet the criteria established for modification of equipment (par. 7-2.5.1) are then implemented in the fielded materiel through the equipment modification process.

7-4.1 IMPROVEMENT PROGRAMS

Requirements for equipment improvement programs are generated by a variety of causes. Validated requirements are satisfied either by a development equipment or by a formal equipment program.

7-4.1.1 Requirement

Since the perfect piece of equipment has yet to be designed, improvements normally are required after an item has been manufactured and delivered. Materiel that functions perfectly during evaluation and test frequently develops problems when placed in the hands of the user and operated in a field environment. Occasionally, manufacturers of critical components go out of business, and substitute replacement items must be found. State-of-the-art developments often call for redesign of assemblies to perform the same function in a more efficient or economical manner, and operational mission objectives are subject to change because of political and strategic fluctuations. These and similar factors generate requirements for improvement programs.

Theoretically, the improvement program has its beginning in the conceptual phase of system development when one idea is superseded by another or better way of performing a function. It also could be considered as continuing through the advanced development and engineering development stages when components are discovered not to function as conceived. It also progresses through the production stage to provide for adaption to the manufacturing processes. It has its real formal beginning, however, when the equipment is delivered to the user and put into operation in a field environment.

7-4.1.2 Configuration Control

Configuration management is a system for recording the established requirements for materiel, making certain that no changes satisfying these requirements are made without proper authority, insuring that all changes are reviewed for total impact and cost effectiveness, and maintaining adequate records of engineering requirements and hardware status. Upon identification of the baseline (the functional baseline documented in the system description, the allocated baseline documented in the development description, and the product baseline documented in the production description), the defining documents are not changed without the coordination, evaluation, approval, and release of configuration change documents. These documents must be coordinated with and analyzed and evaluated by each system engineering functional organization. The success of configuration management is dependent upon the adequate and complete configuration identification, configuration control, and configuration status reporting throughout the life cycle.

The change process, whether related to a development equipment or formal equipment program, is basically the same. The manner of implementation of the change is the varying factor. In the development equipment program, the changes are incorporated after problem identification, design solution, and change approval. In the formal equipment program, the same process takes place, except that the changes are incorporated in a hardware configuration category (e.g., block configuration or category configuration), either based on serial number series or on preplanned evolutionary configuration. The process for each of these programs is discussed in the paragraphs that follow.

7-4.1.21 Development Equipment Program

When the user in the field discovers an equipment fault or shortcoming through operational usage, the deficiency is reported on standard forms through 'channels to the materiel Commodity Manager. At this level, the report is analyzed to determine if prescribed procedures were followed, if environmental use conditions were within system tolerances, if there is an economical advantage in correcting the problem, and the precise cause of the user's dissatisfaction. Once the precise cause of the report is ascertained, an evaluation is made of the most advantageous method for alleviating the situation. The solution may be as simple as informing the user to follow prescribed operating or maintenance procedures, or revising or amplifying the existing procedures. A conclusion that the report concerns a random failure could result in no change action. The user's ,report, however, frequently uncovers a design deficiency that must be corrected by a design change to the equipment. When the evaluation and analysis determine that a change is necessary, design effort is instituted to provide the best corrective solution to the reported problem. This solution considers the total input to the system performance, support, and other operational factors.

The new design is then reviewed, primarily for economic considerations, and, when the design is approved, the Commodity Manager issues detailed instructions for implementation of the change. When new piece parts are required, they are procured and assembled in kit form, with installation or rework instructions, and are made available for installation. If technical directives are involved, changes may be issued as "pen and ink" change notices or as replacement pages. These changes then are incorporated into the equipment or publications on an "as available" basis.

7-4.1.2.2 Formal Equipment Program

A different method of managing an equipment improvement program is by a formal plan that controls the accumulation of the changes, standardizes the documentation, and systematically implements all changes in a specified time span, usually at one location and under the supervision of the same team. Under this plan, the improvements are generated by the same basic means as the developmental system. However, the improvement design changes are allowed to accumulate and are not issued immediately for installation. State-of-the-art improvements are gathered at the same time, along with those changes that may be generated by alteration of mission objectives. At designated time intervals, the field equipment is removed from service and brought to a modification point, and all accumulated changes are incorporated, not only in the operational hardware, but also in the repair parts and technical directives. The advantages of this method include the monetary benefits of large piece part procurement orders, the time saving realized by opening a piece of equipment only once to incorporate several changes, and the outstanding configuration control obtained whereby multiple changes to equipment form, fit, or function are incorporated by a single configuration change and the operational commander thereby is kept aware of the exact condition and capabilities of his units.

7-4.2. IMPLEMENTING THE IMPROVEMENT PROGRAM

Control of the Army equipment improvement programs has been standardized through directives and universal use of specially developed documentation for that control. The basic elements of control consist of the establishment of the baseline configuration, the improvement identification process, the formal change procedure, and the implementation of the change.

7-4.2.1 Design Baseline

The engineering release record is a compilation of all approved engineering drawings and specifications which make up a system. When a newly designed piece of equipment is added to the system or replaces an existing item, the engineering drawings that depict the item and any peculiar specifications for it are added to the engineering release record only after final approval of the Army command responsible for the system. A need to redesign an item is generated by some type of system requirement. For example, it may be due to continual maintenance problems with the existing design. Ease or simplification of operating procedures, a change or variation in the system mission objectives, or major changes to the state of the art in component design may all be sufficient cause to create an entirely new design for an existing item or to add a new item to the system.

The requirement for a new design is presented to the design team only as an idea or concept. This concept then is developed into a series of engineering drawings and specifications after the team has considered and either accepted or rejected many different approaches to achieving the stated goal. When the designer is satisfied that the drawings are technically correct and meet the requirements, a prototype model usually is constructed. Normally, this translation of a drawing into hardware is accompanied by numerous minor adjustments to the original design. Interference of fasteners with internal harnesses or assemblies, inaccessibility of components, wrong size hardware, nonavailability of certain specified materials, and the like, are revealed at this time and must be corrected. Operational tests of the prototype occasionally will reveal faults in the basic design that prevent it from satisfying the requirements and, consequently, a part or parts must be redesigned. Operation of the prototype also may uncover new areas of improvement that can be incorporated easily at this time. When all of these changes are included in the engineering drawings or specifications, the documents are submitted to the sponsoring Army command for validation. During validation, the new documents are checked carefully to assure completeness, technical accuracy, compliance with specifications, system interface compatibility, inclusion of any new specifications, and conformance with Army documentation requirements. Upon completion of the validation process, the approved documents are entered on the engineering release record as part of the system. Thereafter, the documents are subject to formal configuration control procedures and can be changed only by the engineering change proposal process.

7-4.2.2 Change Identification

The requirement for materiel changes may be identified in equipment performance reports or in equipment improvement recommendations.

7-4.2.2.1 Equipment Performance Report

When newly designed or extensively redesigned equipment is introduced to the military system, the equipment undergoes special evaluation tests. These tests, which include development test, environmental tests, an initial production test, a maintenance evaluation test, and other related tests, are conducted by the U S Army Test and Evaluation Command. TECOM evaluates the performance of the new equipment in a tactical environment and reports to the sponsoring commander on an equipment performance report. Every equipment malfunction observed during the tests, as well as any deviation from the expected performance, is reported on separate equipment performance reports. Recommendations for changes to the technical manuals in the areas of both maintenance and operating procedures also are included in the equipment performance report. Equipment performance reports are classified as (1) Deficiency, (2) Shortcoming, or (3) Suggested Improvement. The sponsoring command must insure that all items classified as deficient are corrected before TECOM will consider the test satisfactory and the item will be allowed to proceed to type classification. While the purpose of the test is to evaluate a new design, anomalies may be encountered on related equipment which previously has been type classified. Equipment performance reports may be submitted on those occurrences as "information only" and the commodity Manager could accept them as general field input improvement suggestions.

7-4.2.2.2 *Equipment Improvement Recommendation (Ref. 4)*

All Army materiel is subject to an equipment improvement recommendation, which is a portion of a maintenance request form. The form is used to report equipment failures and receipt of defective new material, or to propose improvements in materiel. The purpose for submission of an equipment improvement recommendation is to initiate early and effective corrective action. The using organization submits copies directly to the National Maintenance Point. Conditions for submission of a recommendation include but are not limited to the following:

a. A condition or materiel fault that is a hazard to personnel, equipment, and missions

b. When a prescribed installation or maintenance action cannot be accomplished, or when operational characteristics or durability cannot be obtained as a result of faulty design or materials

c. Conditions that are a direct result of below-standard quality of workmanship during manufacture, remanufacture, modification, repair, or overhaul, except for those items qualifying for submission of an unsatisfactory materiel report

d. Deterioration of installed components or operational equipment due to the effects of climatic or environmental conditions

e. Shortcomings and deficiencies encountered during "Y" (developmental) aircraft test and evaluation programs

f. Errors arising from inadequate or insufficient data in technical publications, which, if not corrected, may cause a hazard or be a safety-of-flight condition. (All other shortcomings in technical publications will be reported as described in par. **7-4.2.2.3.)**

g. Conditions that preclude adequate operation of the equipment by operating personnel

h. When equipment does not perform to published operational or maintenance standards

i. Circumstances other than the preceding which warrant reporting.

The submission of equipment improvement recommendations will not be withheld because the Army or manufacturers' letters, manufacturers' representatives, or other media indicate awareness of the observed fault. Nor will they be withheld because other organizations within the command have submitted a recommendation concerning identical faults. The fact of failure is important statistical information that will be weighed to justify the urgency and propriety of corrective action.

Equipment improvement recommendations on aeronautical equipment also will be submitted for any of the following special conditions:

a. An Emergency or Urgent Recommendation will be submitted for any condition involving safety of flight or hazard to personnel safety.

b. If suspected or confirmed materiel failure is the cause of an aircraft accident, an Emergency Action recommendation immediately is dispatched. The recommendation will include all available failure data and the name and telephone number of the individual who can be contacted for additional information.

c. A routine equipment improvement recommendation (EIR) must be submitted when a flight abort resulted from a materiel failure or malfunction, but the submittal of an emergency recommendation is not warranted. The routine EIR must reference the crash facts message and identify the cause of flight abort.

d. Equipment improvement recommendations must be submitted for items adjudged to be defective due to dimensional, material, hardness, finish, or performance deviations from the original manufacturing or overhaul rework specifications for the items.

e. Equipment improvement recommendations should be submitted against recurring problems requiring an excessive amount **of** attention for which a solution or fix does not appear to be forthcoming.

f. Equipment improvement recommendations must be submitted when requested by the National Maintenance Point. A request **of** this type reflects that a problem of significant magnitude is suspected to exist, and the recommendation is necessary to confirm and identify the full extent of the problem.

To insure appropriate processing of equipment improvement recommendations, they are assigned priorities as follows:

a. Emergency recommendations report unsafe conditions that are known or believed to exist, which, if uncorrected, could result in fatal or serious injury to personnel or extensive damage or destruction of valuable property, or could have serious adverse effects on national security.

b. Urgent recommendations report potentially hazardous conditions, known or expected to exist, which could result in serious injury to personnel or damage to valuable property, or could reduce combat effectiveness. Such conditions compromise safety and embody risks calculated to be tolerable within reasonable limits only if affected equipment is continued in operation with extreme caution.

c. Routine recommendations report all other conditions'pertaining to equipment or procedures requiring improvement.

Emergency equipment improvement recommendations are transmitted by electrical message or telephone directly to the National Maintenance Point. A followup written recommendation marked EMERGENCY is submitted by Air Mail within 5 working days to the same address. Urgent equipment improvement recommendations are sent by Air Mail and routine recommendations are sent by regular mail to the appropriate National Maintenance Point.

When appropriate, the defective item reported is retained by the user as an equipment improvement recommendation exhibit to assist in the investigation and analysis of the reported problem. These exhibits permit the National Maintenance Point to perform analytical teardowns that frequently reveal faults that normally are not detected during routine repair and overhaul.

7-4.2.2.3 Interface Considerations of Proposed Changes

The evaluation of suggested equipment improvements must be undertaken in consideration of the fact that the fielded item has been the subject of extensive planning in the area of support prior to military acceptance. Concurrence that the suggestion will improve performance is only the beginning; thereafter, a determination must be made of the system costs that would be incurred if the change were made. This means that all of the factors that were part of the original design must be reexamined to ascertain any deviations that would result from implementation of the change. As the design changes develop, they are reviewed by the maintainability engineer to determine the effects on quantitative and qualitative maintenance parameters, not only for the item being changed but also for the system as a whole. The maintainability engineer also contributes to the design to assure that it incorporates the best maintainability features. The maintenance engineer then reviews the design changes for conformance with the system maintenance concept, and to assure that it can be maintained with the tools that are available in the system or to determine the new tools or materials that would have to be added. Provisioning personnel contribute cost impact with regard to new repair parts that will be needed and the parts that will become obsolete and deleted from the system. The training curriculum for both user and maintenance personnel also would have to be revised to include instruction in the new materiel, with a possible impact of lengthening of the courses or a requirement for new training devices. A great impact of any change is the requirement to revise the technical manuals that describe the equipment, detail the procedures for use, and provide instructions for maintenance. In addition to these integrated logistic support costs, other items that add to the total cost of a change are the cost of drawing and specification changes, procurement of piece parts for retrofit kits, the manufacturing of new parts, testing of the change, and, finally, any costs incurred in the actual field retrofit. Only after compilation of the total impact of the change on the system can the Commodity Manager properly evaluate the benefits to be gained by incorporating a suggested equipment improvement. As a result of this total system analysis, the change, although it may appear meritorious on its own, may not be justifiable in terms of its impact on total cost or performance.

I

7-4.2.2.4 *Recommended Changes to DA Publications Form*

The user submits the form to the Commodity Manager to report errors, omissions, or recommendations for improving technical publications. Upon receipt, it is evaluated as any other equipment improvement recommendation, and it may or may not be incorporated in the publication as circumstances warrant.

7-4.2.3 Change *Procedure*

Equipment improvements that necessitate changes, no matter how small, to documents on the engineering release record are governed by the requirements of MIL-STD-480 (Ref. 10), which provides for maintaining configuration control of the system items. That standard establishes configuration control requirements that apply during the development, production, and deployment phases of items that are developed, designed, or modified specifically for Department of Defense activities. It also is used to control the form, fit, and function of privately developed items used in the military product. The document used to identify the technical data package and impact on the system is the engineering change proposal.

The steps prescribed in processing an engineering change consist of the following:

a. Determination of a need for the change

b. Establishment by the originator of a classification of the engineering change as a Class I or Class II

c. Preparation of an engineering change proposal

d. Submittal to the Government

e. Review

f. Approval/disapproval or concurrence/nonconcurrence in classification

g. Incorporation of the approved engineering changes in the item and in the data, including, when applicable, negotiation into the contract.

The engineering change is classified either Class I or Class II based on designated classification criteria. A change is classified Class I if any of the following factors are affected: the functional or allocated configuration identification; the product configuration identification as contractually specified (excluding reference drawings); technical requirements contained in the product configuration identification as contractually specified; nontechnical contractual provisions; and other factors (i.e., safety, computer programs, training devices/equipment, and interchangeability). Any engineering change that does not fall within the Class I definition is classified as Class 11. Examples of Class II changes include documentation-only changes, such as correction of errors or addition of clarifying notes and views; and changes to hardware, such as substitution of materials, which do not create the condition for a Class I change.

To determine the relative speed with which a Class I engineering change proposal is reviewed and evaluated and with which an approved engineering change is ordered and implemented, the originator assigns one of three priorities: emergency, urgent, or routine.

An "emergency priority" is assigned to a change that (1) if not effected without delay, may compromise the national security seriously, or **(2)** corrects a hazardous situation that may result in fatal or serious injury to personnel or in extensive damage or destruction of equipment. An "urgent priority" is assigned to a change that (1) may affect operational characteristics to insure maximum effectiveness, **(2)** correct potentially hazardous conditions, **(3)** meet specific contract requirements, **(4)** avoid delay in schedule or increase cost, or **(5)** result in net life cycle cost savings to the Government. A "routine priority" is assigned to all engineering proposals not classified emergency or urgent.

Class I engineering change proposals are coded to establish the justification for the engineering change. For example, standard codes **(A,** B, **V,** etc.) are used to indicate that a change will correct deficiencies; make a significant effectiveness change in operational or logistic support activities; effect substantial life cycle cost savings; or prevent slippage in an approved production schedule. The justification codes usually are not pertinent to a Class II engineering change proposal and are not assigned. Class II proposals may be initiated when the originator considers that it will benefit him or the Government and is not detrimental to the Government.

Class I engineering change proposals may be submitted to the Government in either of two types appropriate to the circumstances. A Type P (preliminary) engineering change proposal may be submitted to the Government for tentative approval prior to the availability of the detailed information necessary to support the formal change. Preliminary proposals usually are only descriptive in nature, containing listings of the drawings affected and budgetary cost estimates. They are prepared and submitted to furnish the procuring activity with available information in order to permit a preliminary evaluation relative to the merits of the proposed change and a determination regarding the desirability of continuing expenditures required to develop the proposal. Preliminary engineering change proposals also may be submitted to permit a choice of various alternative proposals. A Type F (formal) engineering change proposal provides engineering information and other data in sufficient detail to support formal change approval and contractual authorization. Approved preliminary engineering change proposals are followed by the submittal of formal proposals. The engineering change proposal form (DD 1692) is used for submittal of all types and classes of engineering change proposals. Use of the form and the various pages therein is delineated for the various phases of a program in Table **7-3.** The paragraphs that follow briefly describe page usage for a Class I change during the several program phases.

For Class I changes during engineering or operational system development:

a. Page **1** of the engineering change proposal form is used as the cover sheet to summarize the proposed change. If prototypes of items are undergoing operational evaluation or service tests, changes in the hardware of such existent or subsequent prototype models are described on Page **3** of the form (or on enclosures referenced thereon).

b. Page **2** of the engineering change proposal form is used to describe changes from the functional configuration identification or allocated configuration identification defined by the system specification and each pertinent item specification. **As** required, the detailed text of proposed changes in each of these specifications is furnished as enclosures, but blocks on Page **2** of the form are completed to summarize the significant effect on specifications.

For Class I changes during production or deployment:

a. Page **1** of the engineering change proposal form is used as the cover sheet to summarize the proposed change.

b. Page **3** of the engineering change proposal form is used to describe the effects of the proposed change on the product configuration identification data. The changes in the parts and/or assemblies of the item are described on Page **3** of the form (or on enclosures referenced thereon).

c. Page **4** of the engineering change proposal form is used to tabulate the net life cycle cost impact of the individual change proposal. Entries in the column headed "Other Costs/Savings to the Government" need be made only to the extent that estimated costs/savings data can be determined by the contractor.

d. Page 5 of the engineering change proposal form is applicable either when there are related change proposals or when new trainers or support equipment will be required as a result of the proposed change. The net total life cycle cost impacts (increase or decrease) of the individual related change proposals are summarized on Page 5, together with all related integrated logistic support costs which have not been included in the individual change proposals. Entries regarding related change proposals of other prime contractors are made by integrating contractors; otherwise, such entries need be made by a prime contractor only to the extent that such data are available to the prime contractor.

e. Page **6** of the engineering change proposal form is required if there is a revision in the scheduled actions other than delivery of the item which is the subject of the change proposal. Page **6** is not required if the revision in schedule can be described fully either in Block 19 of Page 1 or by reference therein to a revised schedule for the subject item. When required, Page **6** is used as a graphic presentation of the time phasing of major actions involved in all related engineering changes in hardware and associated updating of documentation.

TABLE 7-3. ENGINEERING CHANGE PROPOSAL (ECP) FORM PAGE UTILIZATION

DD Form Page No.	Title	Validation	Engineering or Operational Development	Production or Deployment
1692 Page 1	Cover sheet	REQUIRED Cover sheet summarizes the ECP.	REQUIRED Cover sheet summarizes the ECP.	REQUIRED Cover sheet summarizes the ECP.
1692-1 Page 2	Functional/allocated configuration identification	REQUIRED USED to: Describe proposed changes in functional configuration identification.	REQUIRED USED to: Describe proposed changes in functional or allocated configuration identification as defined by system and appropriate item specifications.	REQUIRED if:, (a) System specification change is associated with design change. (b) Two-part specification method is used and part I specification needs to be changed. (c) Development and product fabrication specifications are used and development specification needs to be changed.
1692-2 Page 3	Product configuration identification	NOT REQUIRED	REQUIRED when: Prototypes are undergoing operational or service testing. USED to: Describe changes to hardware.	REQUIRED USED to: Describe effects of change in product configuration identification and changes in parts and/or assemblies.
1692-3 Page 4	Cost (one item)	NOT REQUIRED	NOT REQUIRED	REQUIRED USED to: Tabulate cost impact.
1692-4 Page 5	Cost summary	NOT REQUIRED	NOT REQUIRED	REQUIRED if: (a) There are related ECP's applying to two or more items. (b) New trainers or items of support equipment are required. USED to: Summarize cost impact of all related ECP's.
1692-5 Page 6	Milestone chart	NOT REQUIRED	NOT REQUIRED	REQUIRED if: There is a schedule change in more than delivery date for item. USED to: Show interrelationships of schedules.

f. Page 2 of the engineering change proposal form is applicable to changes during the production or operational periods only when changes in the system specification(s), part item specification, or product fabrication are associated with design change.

An example of the use of engineering change proposal forms to effect **a** Class I change during the deployment phase is contained in Figs. **7-3** through 7-8. For this example, Pages 2, 5, and 6 were not required because there was no change in the specification, no related engineering change proposals, no effect on the production schedule, and no new trainers or support equipment required. However, the pages are included to depict their formats. Enclosure I referenced in Figs. **7-3** and 7-5 and Enclosures II and III referenced in Fig. 7-5 describe the effects of the change on various program elements. This is shown in Fig. 7-5, where it may be seen that Enclosure I describes the impact on drawings, maintenance procedures, repair parts, etc., and Enclosures II and III deal with reliability and electromagnetic interference, respectively. The enclosures are not included, but they were used as the basis for cost estimates pertaining to the change. The abbreviations appearing on the forms are self-explanatory, save for the abbreviations listed and defined as follows:

SAIE – Special Acceptance Inspection Equipment

SQAP – Supplemental Quality Assurance Procedure

IRPRL – Initial Repair Parts Requirement List

The applicable functional areas of responsibility—such as engineering, quality, manufacturing, product assurance, logistics, maintenance engineerihg—impacted the engineering change proposal in relation to the effect on the existing materiel support subsystem and/or design. The net cost impact of this change was then delineated on DD Form 1692-3[1] if other related engineering change proposals had affected this package, the total cost would have been summarized on DD Form 1692-4.[2]

The completed package was then reviewed by the Commodity Command for determination of the approval or disapproval of the change. The change was approved as indicated in Block 24a of DD Form 1692[3](Fig. **7-3).**

Receipt of contractual approval of a Class I engineering change proposal, unless otherwise specified by the procuring activity, constitutes the sole authority for the contractor to effect the change. If the procuring activity or purchasing office is not the military activity responsible for technical requirements, the concurrence of such military activity must be obtained prior to contractual action. Approval of the proposal and authorization of the change granted by the Government include reference to the proposal by number, revision, or correction, if applicable, and date.

Class II changes will be reviewed only by the Government for concurrence in classification unless otherwise specified by the procuring activity. When a DD Form 1692 describing a Class II change is submitted for concurrence in classification to the procuring activity, it shall be concurrent with, or prior to, release of the Class II engineering change within the contractor's own plant. When the procuring activity has required by contract provisions that each Class II change be approved by the Government, the contractor does not implement the change until he receives a copy of DD Form 1692, Page 1, showing such approval.

When the Government disapproves an engineering change proposal, the contractor is so notified in writing, with the detailed reasons for the disapproval.

7-4.2.4 Improvement Implementation

Those improvements that are generated during the preproduction phase of the equipment are effected directly into the assembly line with no accompanying forms necessary other than the latest approved engineering documentation. Improvements that are approved after the equipment has been accepted by the military may be incorporated through a retrofit program, whereby the fielded items are altered or modified as discussed in par. 7-2.5.

7-4.2.4.1 *Modification Work Order*

The vehicle by which the retrofit is accomplished is the modification work order. This

[1] DD Form 1692-3 (Engineering Change Proposal)

[2] DD Form 1692-4 (Engineering Change Proposal)

[3] DD Form 1692 (Engineering Change Proposal)

ENGINEERING CHANGE PROPOSAL, PAGE I
(SEE MIL-STD-480 FOR INSTRUCTIONS)

DATE PREPARED: 20 April 1973

PROCURING ACTIVITY NO.

1. ORIGINATOR NAME AND ADDRESS
John Doe Incorporated
Orlando, Florida 32805

2. CLASS OF ECP: I

3. JUST. CODE: O

4. PRIOR.: R

5. ECP DESIGNATION

a. MODEL/TYPE	b. MFR. CODE	c. SYS. DESIG.	d. ECP NO.	e. TYPE	f. REV.	g. CORR.
Pla	04930	Pershing	MI-75302	F	N/A	N/A

6. BASELINE AFFECTED: N/A
☐ FUNCTIONAL ☐ ALLOCATED ☐ PRODUCT

7. OTHER SYS./CONFIG. ITEMS AFFECTED
☐ YES ☐ NO

8. SPECIFICATIONS AFFECTED - TEST PLAN	MFR CODE	SPEC./DOC. NO.	SCN
a. SYSTEM	-	N/A	-
b. ITEM	-	N/A	-
c. TEST PLAN	-	N/A	-

9. DRAWINGS AFFECTED MFR CODE	NUMBER	REV.	NOR NO.
-	See Encl. I,	-	-
-	Para. A	-	-
-		-	-

Slave Starting Power Station

ITEM 0012

12. CONFIGURATION ITEM NOMENCLATURE
RP

13. IN PRODUCTION
☐ YES ☐ NO

14. NAME OF PART OR LOWEST ASSEMBLY AFFECTED
See Block 9

15. PART NO. OR TYPE DESIGNATION
See Block 9

SAMPLE

17. NEED FOR CHANGE
To prevent possible filter burn out during Power Station starting, and provide capability for continuous slave cable connection.

Note: All elements of pages 2, 5 & 6 have been considered and been found not applicable and are therefore excluded.

18. PRODUCTION EFFECTIVITY BY SERIAL NUMBER
RP 0600I and Up

19. EFFECT ON PRODUCTION DELIVERY SCHEDULE
No effect

20 RETROFIT

a. RECOMMENDED ITEM EFFECTIVITY
See Block 40

b. ESTIMATED KIT DELIVERY SCHEDULE
October 1973

c. SHIP/VEHICLE CLASS AFFECTED
-

d. LOCATIONS OR SHIP/VEHICLE NUMBERS AFFECTED
-

21 ESTIMATED COSTS/SAVINGS UNDER CONTRACT

22 ESTIMATED NET TOTAL COSTS

23 SUBMITTING ACTIVITY AUTHORIZING SIGNATURE
John Smith

TITLE
Contractor Authorizing Official

☒ APPROVAL RECOMMENDED ☐ APPROVED ☐ DISAPPROVED ☐ CONCUR IN CLASSIFICATION OF CHANGE ☐ DO NOT CONCUR IN CLASSIFICATION OF CHANGE

c. GOVERNMENT ACTIVITY
U. S. Army Missile Command

SIGNATURE

DATE
4-22-73

FORM
DEC 68

Figure 7-3. DD Form 1692

ENGINEERING CHANGE PROPOSAL, PAGE 2
(SEE MIL-STD-480 FOR INSTRUCTIONS)

PROCURING ACTIVITY NO.

ORIGINATOR NAME AND ADDRESS

ECP NUMBER

25. OTHER SYSTEMS AFFECTED

26. OTHER CONTRACTORS/ACTIVITIES AFFECTED

28. EFFECTS ON PERFORMANCE ALLOCATIONS AND INTERFACES IN SYSTEM SPECIFICATIONS

29. EFFECTS ON EMPLOYMENT. INTEGRATED LOGISTIC SUPPORT, TRAINING, OPERATIONAL EFFECTIVENESS, ETC.

30. EFFECTS ON CONFIGURATION ITEM SPECIFICATIONS

SAMPLE

31. DEVELOPMENTAL REQUIREMENTS AND STATUS

32. TRADE OFFS AND ALTERNATIVE SOLUTIONS

33. DATE BY WHICH CONTRACTUAL AUTHORITY IS NEEDED

DD FORM 1 DEC 66 1692-1

D-11686

Figure 7-4. DD Form 1692-1

ENGINEERING CHANGE PROPOSAL, PAGE 3
(SEE MIL-STD-480 FOR INSTRUCTIONS)

PROCURING ACTIVITY NO.

ORIGINATOR NAME AND ADDRESS
John Doe Incorporated
Orlando, Florida 32805

ECP NUMBER
MI-75302

(X)	FACTOR		ENCL.	PAR.	(X)	FACTOR		ENCL.	PAR.
	34. EFFECT ON PRODUCT CONFIGURATION IDENTIFICATION OR CONTRACT				X	Retrofit Kits	See Block 40		
	PERFORMANCE	N/A							
	WEIGHT-BALANCE-STABILITY *(Aircraft)*	N/A				36. EFFECT ON OPERATIONAL EMPLOYMENT			
	WEIGHT-MOMENT *(Other equipment)*	N/A				SAFETY	N/A		
X	DRAWINGS		I	A		SURVIVABILITY	N/A		
	NOMENCLATURE	N/A			X	RELIABILITY		II	
						MAINTAINABILITY	N/A		
						SERVICE LIFE	N/A		
	35. EFFECT ON INTEGRATED LOGISTIC SUPPORT (ILS) ELEMENTS					OPERATING PROCEDURES	-		
	ILS PLANS	N/A			X	ELECTROMAGNETIC INTERFERENCE		III	
	MAINTENANCE CONCEPT AND PLANS	N/A				ACTIVATION SCHEDULE	N/A		
X	MAINTENANCE PROCEDURES		I	B		OPERATING INSTALLATIONS	-		
	INTERIM SUPPORT PROGRAM	N/A							
X	SPARES AND REPAIR PARTS		I	C					
X	TECH. MANUALS/PROGRAMMING TAPES		I	D		37. OTHER CONSIDERATIONS			
X	FACILITIES		I	E		INTERFACE	N/A		
	SUPPORT EQUIPMENT	N/A				OTHER AFFECTED EQUIPMENT/GFE	N/A		
	OPERATOR TRAINING	N/A				PHYSICAL CONSTRAINT	N/A		
	OPERATOR TRAINING EQUIPMENT	N/A				OPERATIONAL COMPUTER PROGRAMS	N/A		
X	MAINTENANCE TRAINING		I	F		REWORK OF OTHER EQUIPMENT	N/A		
	MAINTENANCE TRAINING EQUIPMENT	N/A			X	SYSTEM TEST PROCEDURES		I	K
	PERSONNEL	N/A			X	SAIE		I	A&H
	CONTRACT ENGINEERING TECH. SVCS.	N/A			X	SQAP		I	A&H
X	VERIFICATION AND DEMONSTRATION PLANS		I	G					

38. ALTERNATIVE SOLUTIONS
-

SAMPLE

39. DEVELOPMENTAL STATUS
-

40. RECOMMENDATIONS FOR RETROFIT
MWO 5-1450-204-30/1. RP 05001-05083, 05201-05242. Requirement for 130 kits, kit number 5420099. Installation of kits for RP 04001-04005 will be taken care of during the MOD & IRON program. Formal manuscript & Final Kit drawing available. MWO Required Yes X No

41. MAN-HOURS PER UNIT TO INSTALL RETROFIT KITS
a. ORGANIZATION -
b. INTERMEDIATE -
c. DEPOT -
d. OTHER 56 Hrs.

42. MAN-HOURS TO CONDUCT SYSTEM TESTS AFTER RETROFIT
2 Hours

43. THIS CHANGE MUST BE ACCOMPLISHED
☐ BEFORE ☐ WITH ☐ AFTER THE FOLLOWING CHANGES
-

44. IS CONTRACTOR FIELD SERVICE ENGINEERING REQUIRED?
☒ YES ☐ NO Encl. 1, para. I

45. OUT OF SERVICE TIME
See Encl. I, para. J.

46. EFFECT OF THIS ECP AND PREVIOUSLY APPROVED ECP'S ON ITEM

47. DATE CONTRACTUAL AUTHORITY NEEDED FOR PRODUCTION N/A

DD FORM 1 DEC 64 1692-2

Figure 7-5. DD Form 1692-2

ENGINEERING CHANGE PROPOSAL, PAGE 4
(SEE MIL-STD-480 FOR INSTRUCTIONS)

PROCURING ACTIVITY NO
SUMMARY

ORIGINATOR NAME AND ADDRESS
John Doe Incorporated
Orlando, Florida 32805

ECP NUMBER
MI 75302

FACTOR	COSTS/SAVINGS UNDER CONTRACT					OTHER COSTS/SAVINGS TO GOVERNMENT
	NON-RECURRING	RECURRING			TOTAL	
		UNIT	QUANTITY	TOTAL (RECURRING)		
	(1)	(2)	(3)	(4)	(5)	(6)
a. PRODUCTION COSTS/SAVINGS						
CONFIGURATION ITEM						
FACTORY TEST EQUIPMENT						
SPECIAL FACTORY TOOLING						
SCRAP						
ENGINEERING, ENGRG. DATA REV.						
REVISION OF TEST PROCEDURES						
QUALIFICATION OF NEW ITEMS						
SUBTOTAL OF PROD. COSTS/SAVINGS						
b. RETROFIT COSTS						
ENGINEERING, ENGRG. DATA REV.						$ 10,852
PROTOTYPE TESTING						705
KIT PROOF TESTING						
RETROFIT KITS		$ 397	130	$ 51,610	$ 51,610	
PREP. OF MWO/TCTO/SC/ALT INSTR.						
SPECIAL TOOLING FOR RETROFIT						
CONTRACTOR FIELD SERVICE ENGRG						
INSTALLATION						70,070
TESTING AFTER RETROFIT						2,503
MODIFICATION OF GFE						1,988
SQAP						2,759
SAIE						1,836
SUBTOTAL OF RETROFIT COSTS				$ 51,610	$ 51,610	
c. INTEGRATED LOGISTIC SUPPORT COSTS/SAVINGS						
SPARES/REPAIRS PARTS REWORK						
NEW SPARES AND REPAIR PARTS						
RETROFIT KITS FOR SPARES						
OPERATOR TRNG. COURSES						
MAINTENANCE TRNG. COURSES						
REV. OF TECH. MAN./PROGRAMMING TAPES						18,077
NEW TECH. MAN./PROGRAMMING TAPES						
PREP. OF MWO/TCTO/SC/ALT INSTR.						8,108
INTERIM SUPPORT						
MAINTENANCE MANPOWER						
PMAC						140
IRPRL						527
SUBTOTAL OF ILS COSTS					$ 51,610	117,655
d. OTHER COSTS/SAVINGS						
e. SUBTOTAL COSTS/SAVINGS						
SUBTOTAL UNDER CONTRACT						
f. COORDINATION CHANGES BY OTHER CONTRACTORS						
g. COORDINATION CHANGES BY GOVERNMENT						
ESTIMATED NET TOTAL COSTS						$ 169,265

SAMPLE

DD FORM 1 DEC 68 1692-3

D-11686

Figure 7-6. DD Form 1692-3

ENGINEERING CHANGE PROPOSAL, PAGE 5
(SEE MIL-STD-480 FOR INSTRUCTIONS)

PROCURING ACTIVITY NO.	
ORIGINATOR NAME AND ADDRESS	ECP NUMBER

49. ESTIMATED COSTS/SAVINGS SUMMARY, RELATED ECP'S (USE MINUS SIGN FOR SAVINGS)	MANUFACTURER'S CODE (1)	ECP NUMBER (2)	COSTS/SAVINGS UNDER CONTRACTS (3)	OTHER COSTS/SAVINGS TO GOVERNMENT (4)
a. PRODUCTION COSTS/SAVINGS *(Subtotal of Costs/Savings Elements from block 48a applicable to aircraft, ship, tank, vehicle, missile or its subsystem)*				
SUB-TOTAL PRODUCTION COSTS/SAVINGS				
b. RETROFIT COSTS *(Applicable to aircraft, ship, tank, vehicle, missile or its subsystem)*				
SUB-TOTAL RETROFIT COSTS				
c. INTEGRATED LOGISTIC SUPPORT COSTS/SAVINGS				
REVISED REQUIREMENTS				
1. ITEM RETROFIT *(If not covered under "b") (Applicable to aircraft, ship, tank, vehicle, missile or its subsystem)*				
5. OTHER TRAINING EQUIPMENT				
6. SUPPORT EQUIPMENT *(Net total cost/saving from each ECP on support equipment)*				
7. ILS PLANS				
8. MAINTENANCE CONCEPT, PLANS, SYSTEM DOCUMENTS				

SAMPLE

NEW REQUIREMENTS	NON-RECURRING COSTS	RECURRING COSTS UNIT	RECURRING COSTS QTY.	RECURRING COSTS TOTAL	COSTS/SAVINGS UNDER CONTRACTS (3)	OTHER COSTS/SAVINGS TO GOVERNMENT (4)
10. PROVISIONING DOCUMENTATION						
11. OPER TRNR/TNG DEVICES/EQUIP						
12. MANUALS/PROGRAMMING TAPES, SPARES, REPAIR PARTS *(For 11)*						
13. MAINTENANCE TRNR/TRNG DEVICES/EQUIPMENT						
14. MANUALS/PROGRAMMING TAPES, SPARES, RPR PARTS *(For 13)*						
15. SUPPORT EQUIPMENT						
16. MANUALS/PRGMG TAPES *(For 15)*						
17. PROV. DOCUMENTATION *(For 15)*						
18. REPAIR PARTS *(For 15)*						
SUB-TOTAL ILS COSTS/SAVINGS *(Sum of c.1 through c.18)*						

	MANUFACTURER'S CODE	ECP NUMBER	COSTS/SAVINGS UNDER CONTRACTS	OTHER COSTS/SAVINGS TO GOVERNMENT
d. OTHER COSTS/SAVINGS *(Total from block 48d of related ECP's)*				
TOTAL OTHER COSTS/SAVINGS				
SUB-TOTALS OF COLUMNS				
SUB-TOTAL UNDER CONTRACT				
e. ESTIMATED NET TOTAL COSTS/SAVINGS *(a + b + c + d)*				

DD FORM 1 DEC 66 1692-4 D-11881

Figure 7-7. DD Form 1692-4

ENGINEERING CHANGE PROPOSAL, PAGE 6 (MILESTONE CHART)
(SEE MIL-STD-680 FOR INSTRUCTIONS)

DATE PREPARED: 1 May 1975

PROCURING ACTIVITY NO:

ORIGINATOR NAME AND ADDRESS: A. B. SEE AIRCRAFT CORPORATION, OKLAHOMA CITY, OKLAHOMA

MFR CODE: 99999

ECP NUMBER: 462-1

CONFIGURATION ITEM NOMENCLATURE: A 267 B AIRCRAFT

TITLE OF CHANGE: LANDING GEAR IMPROVEMENT

DATE AUTHORIZATION TO PROCEED RECEIVED BY CONTRACTOR

SYMBOL EXPLANATION: [S] START DELIVERY [C] COMPLETE DELIVERY ▽ PROGRESS POINT

	NO. OF MONTHS	1–12	13–24	25–36
CONFIGURATION ITEM	PRODUCTION		[S]	
	TECH MANUALS/ PROG TAPES	▽ SF 30	[S]	[C]
	RETROFIT	▽ GOVT REP PLACES KIT CALL	[S] 1ST KIT	LAST KIT [C]
	MWO, TCTO, SC, ALT		PARTS LIST SUBM ▽ [C] TCTO DEL	
	SPARES/REPAIR PARTS		SICR SUBM ▽ ▽ SICR APPROVED	
SUPPORT EQUIPMENT	PRODUCTION	NIA SAMPLE		
	TECH MANUALS/ PROG TAPES	SF 30 ▽	[S] [C]	
	RETROFIT	GOVT REP AUTH ▽	1ST KIT [S]	[C] LAST KIT
	MWO, TCTO, SC, ALT		PARTS SUBM ▽ TCTD DEL [C]	
	REPAIR PARTS	NIA		
TRAINER	OPERATOR		▽ ENG REL 1ST KIT [S]	
	MAINTENANCE		▽ ENG REL [S] 1ST PROD	

NO. OF MONTHS: 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36

DD FORM 1 DEC 66 1692-5

is an official Department of the Army publication that provides authentic and uniform instructions for altering and modifying Department of the Army materiel. They are Department of the Army directives, and their application is mandatory. Initiation of a modification work order for materiel is the responsibility of the agency responsible for the maintenance support of the materiel. The basic criteria that have been developed for modifications limit them to those required for safety of personnel/equipment and to those which provide significant improvements in the combat or operational effectiveness of the equipment. Those modification work orders that are required to assure safety of personnel or to prevent serious damage to equipment are classified URGENT. When this classification is assigned, all applicable materiel, including that in stock, is declared inoperable immediately; no item to which the modification work order applies may be used or issued until the modification has been accomplished. When special circumstances warrant, the Commodity Command may allow continued operation of the materiel to which the work order applies under specific precautionary measures for periods of up to 120 days. Under these special conditions, materiel in stock cannot be issued until the modification has been applied.

All other modification work orders that do not meet the requirements for an URGENT classification are classified NORMAL. Work orders classified NORMAL are accomplished on all applicable equipment assigned to active Army units, and to similar equipment in stock or assigned as maintenance float items. Items in stock cannot be issued or used until the modification has been applied. To as great a degree as possible, work orders classified NORMAL are applied to unserviceable economically repairable items at the time those items are repaired, overhauled, or rebuilt.

The maintenance engineering activities of the sponsoring agencies direct the technical development of the MWO based upon the approved Engineering Change Proposal (ECP). The modification work order prescribes all technical requirements for accomplishing the modification and includes as a minimum:

a. Identification number, title, and classification of the order

b. Effective date of the order

c. Purpose of the modification

d. Modification procedure

e. Weight and balance data

f. Prerequisites; i.e., those modifications which must be accomplished prior to or concurrently with a particular order

g. Technical manuals, technical bulletins, supply bulletins, depot maintenance work requirements, and other technical publications affected

h. Estimated downtime of the end item for accomplishment of the work

i. Lowest category of maintenance authorized to accomplish the modification to end items, modules, and parts, as applicable

j. Nomenclature, stock number, and serial numbers of the affected end items, modules, and parts

k. Number of personnel by MOS and manhours required to accomplish the modification of one end item, module, or part, as appropriate

l. Special tools, tool kits, or facilities required to accomplish the modification

m. The modification work order kit number, kit contents, and quantity of kits required for the modification of one end item, module, or part, as appropriate

n. Bulk items required from local supply sources to accomplish the modification

o. Repair parts added and/or deleted by stock number and/or part number, nomenclature, and unit cost

p. Recording and reporting requirements

q. A time compliance date by which all modifications are expected to be completed.

Prior to the publication of a modification work order or depot maintenance work requirement authorizing mass accomplishment of a p proved modifications or the quantity procurement of kits or items for kits, the proposed change will be subjected to appropriate testing. This testing includes the trial application of a prototype modification kit in accordance with the detailed procedures and using the tools and methods contained in a draft manuscript of the work order. Only after this verification process is the modification work order published to authorize the accomplishment of the approved modification. Modification work orders that are to be applied by a contractor or depot maintenance facility are assigned a modification work order number, but are published as a depot maintenance work requirement or contract work statement, as appropriate. Once approved and published, a work order is changed only to correct basic errors or deficiencies or to extend the application range of serial numbers of materiel affected by the original document.

7-4.2.4.2 *Equipment Improvement Report and Maintenance Digest*

Minor alterations that do not qualify for modification work order or official modification program can be implemented into fielded equip ment by various means. An official letter type of directive, for example, from the ,Commodity Manager outlining the details of the improvement permits the user to incorporate it at his convenience. A more formal method, but subject to less stringent control than the modification work order, uses the Equipment Improvement Report and Maintenance Digest. This digest is published quarterly by the major Commodity Commands in a standardized Department of the Army Technical Bulletin format. It is directive in nature and contains a summary of equipment improvement recommendations received during the quarterly reporting period, listed by major command and pertinent subordinate commands. It provides a continuous update on all open case entries until closed. It provides users of the equipment and maintenance personnel with all pertinent information reflecting trends of organizational and direct and general support maintenance problems experienced, and the actions taken to resolve them, including the media for providing such detailed data. The Equipment Improvement Report and Maintenance Digest also may authorize the accomplishment of minor alterations to equipment, giving all essential details for making the change, the tools required, the source of piece parts, and testing and recording the modification. When such alterations are directed, the applicable technical manuals subsequently will be changed to reflect the new configuration.

7-4.2.4.3 *PS Magazine*

Another method of disseminating information regarding minor equipment improvements is by means of the *PS Magazine* issued monthly. The areas involved are primarily those of operating or maintenance procedures. The *PS Magazine* is a small pocket-size pamphlet, printed in bright colors and featuring eye-catching cartoons and comic strip story line—all designed to attract the eye of the soldier to whom the subjects are addressed. The magazine provides a means of highlighting essential maintenance features for continued satisfactory equipment operation, hints on how to ease the preventive or corrective maintenance tasks, operating faults that have caused equipment failures, and similar topics that the immediate user would find interesting. Articles frequently are provided on the construction of simple tools that would ease the performance of some tasks. Minor equipment changes, such as the fabrication and installation of switch guards or the changing of knob sizes, are suggested if the unit is experiencing a certain type of problem. The *PS Magazine* also is used to provide advance information about incorrect stock numbers, superseded or obsolete items, changed information in technical manuals, changes in Commodity Managers, etc., for use until the official documentation is revised and published. All Commodity Commands provide inputs to the *PS Magazine* to pass the ‘word to their individual user to obtain improved equipment performance. A “letters to the editor” section allows the soldier to ask questions regarding any troublesome area; the answers are authoritative in nature, providing an official response to his problem. Although it is very informal in appearance, the *PS Magazine* is a useful tool in the US Army equipment improvement program.

REFERENCES

1. **FM 38-5,** *Logistics Maintenance Management,* **May 1969.**
2. **FM 38-7,** *Logistics Materiel Development Management,* **November 1966.**
3. **NAVORD OD 39223,** *Maintainability Engineering Handbook,* **June 1969.**
4. **TM 38-750,** *The Army Maintenance Management System (TAMMS),* **November 1972.**
5. **TM 5-6115-450-15,** *Operutor, Organixational, DS, GS, and Depot Maintenance Manual, Generator Set, Gasoline Engine: 10 KW, AC, 120/240V Single Phase, 120/208V, 3 Phase, 400 Hertz, Skid Mounted (Less Engine),* **March 1968.**
6. **AMCP 706-134, Engineering Design Handbook,** *Maintainability Guide for Design.*
7. **MICOM 750-8,** *Maintenance of Supplies and Equipment,* **March 1972.**
8. **AR 71-6,** *Type Classification/Reclassification of Army Materiel,* **July 13, 1973.**
9. **AR 750-1,** *Army Materiel Maintenance Concepts and Policies,* **June 1972.**
10. **MIL-STD-480,** *Configuration Control–Engineering Changes, Deviations and Waivers,* **October 30, 1968.**
11. **AR 750-51,** *Maintenance Assistance and Instruction Team (MAIT) Program,* **31 March 1972.**

BIBLIOGRAPHY

TM 38-750-1, *The Army Maintenance Management System (TAMMS) Field Command Procedures.*

TM 38-750-2, *The Army Maintenance Management System (TAMMS) National Agency Procedures.*

DA PAM 750-1, *PM, Commander's Guide of Preventive Maintenance Indicators,* **January 1971.**

CHAPTER 8
DATA COLLECTION AND DECISION MAKING

This chapter describes several Army data systems und how data jrom the systems are used to make decisions. Trade-offs are discussed, and several trade-off examples are presented. Life cycle costs are examined, with emphasis on support costs. Models for calculating elements of life cycle support costs are defined, and a cost calculation is accomplished.

8-1 INTRODUCTION

Maintenance engineering analysis is a process by which maintenance specialists evaluate the proposed or actual design of materiel to determine the maintenance characteristics and logistic resource requirements for a particular design configuration, and to establish effective techniques and procedures for performing system maintenance. New materiel begins to generate valuable experience data coincident with its initial deployment. These data, if accurately recorded and consistently reported, provide the final basis on which the suitability of the system in the user environment is evaluated. In addition, the reporting system forms the essential basis for an effective feedback loop if provisions are made for continuous reporting and periodic analysis of maintenance experience data throughout the deployment phase, and if formal procedures are established for progressive correction of discrepancies revealed by analysis (Ref. 1).

A data system, as it relates specifically to maintenance performance, may be a part of an overall standard materiel maintenance management system. An effective materiel maintenance management system should provide for (Ref. 2):

a. Responsiveness to the needs of both field commanders and the national level management requirements

b. Automated forecasting, distribution, scheduling, and production control of maintenance workloads commensurate with requirements and resources of major Army commands

c. Collection of necessary data to determine maintenance costs of systems and equipments to maintenance facilities below the depot level

d. Maintaining visibility of the progress and costs associated with materiel modification programs

e. Collection of equipment performance and maintenance performance data on weapon systems and end items to facilitate:

(1) The development of failure patterns and repair factors

(2) Monitoring the materiel readiness conditions of organizations and commands

(3) Forecasting requirements for materiel and maintenance resources

(4) Assessing the efficiency and effectiveness of maintenance operations.

f. Developing and prescribing necessary standard forms and formats for the collection, transmission, and display of information needed in the management of the materiel maintenance and related supply effort.

The collected data are analyzed and used, as required, to:

a. Determine and maintain cognizance of:

(1) Equipment status and materiel readiness

(2) Effectiveness of maintenance operations in the accomplishment of assigned missions to include effectiveness of assignment and use of maintenance manpower, achievement of support maintenance evacuation standards, adequacy and use of operational readiness float, cost of support maintenance, control and status of modification applications and the calibration program, and adequacy of resources to reduce abnormal workload backlogs

(3) Marginal and substandard equipment and/or maintenance performance

(4) Maintenance costs which exceed established parameters

(5) Responsiveness of the supply system to support maintenance operations to include the responsiveness of direct exchange operations.

b. Initiate required management and/or engineering action to correct deficiencies.

c. Provide experience data for engineering evaluation and consideration in the establishment of support parameters for and the design of new equipment, and redesign of current equipment and/or its support subsystem and product improvement.

The collected data should include high-quality information in sufficient quantity and such form as to enable assessment of the various equipment reliability, maintainability, and availability parameters and permit the accomplishment of tasks in other areas as indicated by the following:

a. Maintenance:

(1) Evaluation of equipment deficiencies

(2) Development and revision of maintenance allocations, maintenance float factors, and repair part allowances

(3) Review of maintenance procedures

(4) Ease of m'aintenance review

(5) Development and revision of repair and overhaul criteria

(6) Development and revision of maintenance manpower criteria and standards

(7) Revision of periodic maintenance services

(8) Equipment standardization studies

(9) Equipment and repair part simplification studies

(10) Modification control

(11) Development and review of maintenance requirements and programs.

b. Procurement, production, and quality assurance:

(1) Development and revision of test and acceptance specifications

(2) Adequacy of quality control procedures

(3) Reliability of supply sources

(4) Development and revision of contractual clauses.

c. Supply:

(1) Repair part and maintenance float requirement computations

(2) Materiel programming

(3) Equipment and repair part disposal actions.

d. Training:

(1) Training requirements

(2) Investigation of training problems.

e. Research and development;

(1) Establishment of maintainability and reliability requirements

(2) Redesign of current equipment

(3) Development and review of qualified product lists.

f. Calibration:

(1) Development and revision of calibration procedures

(2) Development and revision of calibration support requirements

(3) Evaluation of test, measurement, and diagnostic equipment.

The maintenance engineer, in performing the analysis function on new items of equipment, is able to facilitate the early decision process and influence the design through the availability of accurate, complete, and comprehensive information existing in the data system on comparative items. The data provide the history and factual backup on which to base the design and support decisions during the conceptual phase.

The requirements for maintainability or maintenance may be derived from the description of operational requirements. Usually, the requirements are specific enough to imply the consideration of one or more alternative maintenance concepts. Historical data on existing or comparative systems should be available to the maintainability and maintenance engineers so that, through mutual interface of trade-offs, the optimum configuration of performance and maintenance resources can be achieved in a cost-effective fashion. It is important that these early estimates, in relation to maintainability or maintenance resource requirements, be realistic in terms of real need, yet consistent with current state-of-the-art design. When compatibility between the need and the design feasibility is so questionable that achievement of maintainability objectives would be classified as high risk, the risk involved must be estimated and its source described (Ref. 1). Major decisions related to the maintenance of materiel which can be formulated based on factual data are substantiated more easily and result in minimizing the risk in relation to performance/support parameters of the materiel.

One of the key data items in the planning and detection of performance, design, and support parameters for materiel is the failure rate data. First and foremost, historical data on similar items are used to form the data base for determination of the failure rate and subsequent reliability requirements of the system. Secondly, the failure rate data are used for:

a. The apportionment and prediction of maintainability requirements based on percent contribution to total failures of items comprising the system

b. The determination of the mean time between failures used in availability calculations

c. The development of fault isolation flows used in the maintenance task analysis to determine the most probable paths for maintenance action

d. The determination and calculation of the failures for the system based on operational and deployment concepts and subsequently used in the determination of:

(1) Maintenance workloads

(2) Resource requirements

(3) Data base for maintainability/maintenance support trade-offs related to concept and design

(4) The maintenance factor.

e. The substantiation for recommended design or support changes to an existing or proposed system.

Data elements required to determine the failure rate consist of but are not limited to the following: detailed identification of the failed item, the period of operation, operational conditions, environment, item disposition at each maintenance level, unusual conditions, and accumulated time or mileage.

8-1.1 MILITARY DATA SYSTEMS

Several military data systems have been developed to aid in the overall materiel management process. These systems include but are not limited to the following:

a. The Army Maintenance Management System, including Sample Data Collection

b. Logistic Support Analysis Data System

c. Depot Maintenance Capability/Capacity and Engineering Data Report

d. Commodity Command Standard System

e. System-Wide Project for Electronic Equipment at Depots, Extended.

Information on the content and application of each of these typical data systems is included in subsequent paragraphs.

8-1.1.1 The Army Maintenance Management System (TAMMS) Including Sample Data Collection (Refs. 3 and 6)

The equipment record procedures known as The Army Maintenance Management System are used for control, operation, and maintenance of selected Army equipment.

8-1.1.1.1 Applications and Exceptions

This system is applicable to:

a. Equipment improvement recommendations

b. Recording and mandatory reporting of all modification work order requirements and accomplishments

c. Recording essential information to be used for evaluation of materiel readiness

d. Recording and reporting of failure data for design of new equipment, redesign of standard equipment, and product improvement

e. Collection of inventory, operational, and/or maintenance data on special one-time studies or projects (In cases where the forms and procedures do not fully meet the requirements of such studies, approval for deviation must be obtained from Headquarters, Department of the Army.)

f. The periodic application by the Department of the Army of a sampling technique to obtain specific organizational maintenance action data from units located in a specific geographic area (This sampling will include only specific type/model/series of equipments for a limited time period.)

The exceptions to the application of the maintenance management system procedures are:

a. Installed equipment to provide utility services such as gas, steam, and water *b.* Industrial production equipment

c. Locally purchased nonstock-numbered, nonstandard (nontype-classified) equipment, other than commercial vehicles

d. Equipment procured with nonappropriated funds.

8.1.1.1.2 Records and Forms

The equipment records for the Army fall into several categories: operational records, maintenance records, equipment historical records, ammunition records, and calibration records.

The several categories of records are complemented by the use of detailed forms to supply the information required. The paragraphs that follow. discuss the purpose and use of the various forms within the data system.

a. Operational Records. Operational records include the following:

(1) The equipment utilization record provides a record for the control of equipment utilization. This record is used to control the use of special-purpose, tactical, or commercial design vehicles, including materiel handling equipment. The information includes equipment identification, uses, time of use, mileage, destination, arrival and departure times, and information related to abnormal occurrences during use.

(2) The organizational control record for equipment provides ready identification of the uses and location of equipment while on dispatch or use. The record is used by dispatchers to record the dispatch of equipment, and by commanders to determine who is requesting and using the equipment, and when it will be returned.

b. Maintenance Records.

(1) The exchange tag is used for direct-exchange purposes and as an identification tag for equipment improvement reports and warranty claim exhibits. The tag is used to identify items throughout the direct-exchange program, items being held for equipment improvement report and warranty claim exhibits, items other than direct-exchange or exhibit items, or as a receipt for items of test and measuring equipment undergoing calibration.

(2) The preventive maintenance schedule and record provides a means for recording scheduled and performed maintenance services required at the organizational maintenance level, and pertinent data required to determine readiness. The record is used for scheduling periodic maintenance services on equipment when the maintenance must be performed by a mechanic or operator personnel under the supervision of maintenance personnel, scheduling calibration services, recording nonavailable time due to supply and maintenance, and recording the results of equipment serviceability criteria.

(3) The equipment inspection and maintenance worksheet is used for recording equipment faults found during the operator's daily inspection and service, periodic maintenance services, inspection of equipment by maintenance activities, diagnostic checkouts and spot check inspections of equipment, equipment serviceability criteria tests and checks, and results of a complete technical evaluation of a guided missile system.

(4) The maintenance request register provides a consolidated record of job orders generated, received, and processed by maintenance activities. At the organizational level, this form is used to maintain a record of support maintenance requests and, at the support level, as an internal shop management record. The form is also used to record and control maintenance requests forwarded to commercial contractors.

(5) The materiel readiness report provides, to Department of the Army Staff and Commanders at all levels, information on the readiness status of equipment in the hands of using organizations.

(6) The maintenance request provides the means to request direct or general support maintenance, record the accomplishment of organizational and direct and general support maintenance, report from all levels the accomplishment of modification work orders on all Army materiel, submit equipment improvement recommendations and warranty claim actions, and serve as a source document for maintenance. These data are used to provide maintenance information to all management levels.

(7) The component removal and repair/overhaul, installation, movement, and condition report provides the means for recording and reporting data required to control selected

aircraft items; combat vehicle engines; and selected nuclear weapons, components, and parts. The data include but are not limited to identification and location of the item, current serviceability status, and major item of equipment on or from which the item is to be installed or removed. This information is used to provide repair, control, and historical data for designated reportable items, whether installed or uninstalled.

(8) The backlog status and workload accounting report provides the unit or organization a record of the days their selected items of equipment were nonoperational for supply or maintenance at support maintenance levels. This record is used by all support maintenance activities to report to the owning unit organization nonoperational supply or maintenance days for all materiel readiness items received on a maintenance request.

c. Equipment Historical Records. These are historical records, in the form of equipment logs, relating to specific items of equipment. The individual record is a control device for the mandatory recording of events during the life cycle of equipment, including receipt, operation, condition, maintenance accomplished, and modification. The most important use of the equipment log is to provide Commanders with up-to-date information concerning the readiness of an item of equipment, the condition of the equipment, and the identification of equipment requiring the greatest maintenance effort.

d. Ammunition Records. These records provide information and data related to the usage, condition, and status of Army munitions–chemical and radiological ammunition materiel, conventional ammunition, and Class V munitions usually containing an explosive element and used in assembling complete missiles and rockets. Records also are maintained on other items used on guided missiles or rockets and on special explosive ordnance disposal tools and equipment.

e. Calibration Records. The calibration data card provides a means for identifying individual calibration standards and test and measuring equipment that requires periodic calibration; a means for scheduling calibration services; a record of man-hours, repair parts, adjustments, and direct man-hours expended during the calibration effort; a report of calibration accomplished; and a data source for management, operational, and equipment reliability information.

8-1.1.1.3 Sample Data Collection

The sample data collection program is a part of The Army Maintenance Management System designed to collect selected data for specific equipments for a designated quantity or percentage of the total density to obtain repair and service data. Sample data will be obtained from specific units located in designated geographical areas for a limited period of time. These data will be used by the equipment proponent for evaluating equipment performance effectiveness.

The objectives of sample data collection are to:

a. Preclude the receipt of gross amounts of data at the national level.

b. Provide for additional improvement of the maintenance management data system.

c. Provide a means for collecting, under controlled conditions, valid data required to assess the performance effectiveness of Army materiel.

d. Improve the quality, accuracy, and timely submission of data used in product improvements and performance assessments.

e. Evaluate the adequacy of supply and maintenance support.

f. Reduce the administrative processes at the data processing installation level and higher that are necessary to obtain maintenance management information.

g. Reduce the volume of maintenance management data to a level that is consistent with the Army's resources to manage it.

The Department of the Army policy pertaining to sample data collection is:

a. Reduce interference with field operations by limiting the number of reporting organizations.

b. Restrict the flow of maintenance management data to the command level that has the responsibility and capability to detect and resolve problem areas.

c. Obtain the minimum amounts of data to provide the confidence level essential to support correct decision making processes at the equipment proponent and national level.

d. Maintain the management visibility necessary at the DA level to restrict data flow and data interchange processes.

e. Introduce sample data collection to all data collection processes at the national level, when possible, and allow for maximum field command analysis of field operational problems.

f. Operate under an approved plan which contains:

(1) Materiel identification

(2) Nature of data to be collected

(3) Method of collection to be used

(4) Duration of collection period

(5) Geographical location

(6) Responsible activities

(7) Availability of data processing capability

(8) Cost estimate and cost-effectiveness justifications

(9) Required confidence levels

(10) Details concerning flow of data and performance of statistical and engineering analysis.

g. Submit sample data collection plans developed for equipment nominated for the application of sampling to Headquarters, DA, for approval.

h. Limit sample data collection programs to new equipment entering the Army inventory or to obtain specific current data on other selected items for life cycle studies and product or support improvement.

i. Use only approved maintenance management data forms to collect data required under the sample data collection program.

The development of each sample data collection plan for each selected item of equipment shall:

a. Provide a complete description of candidate equipment items.

b. Define the nature, purpose, use, and confidence level of the data to be collected.

c. Define the parameters of the equipment informational characteristics desired (e.g., end items, components, assemblies, repair parts).

d. Identify the essential elements of information to be collected and specify the data portrayed requirements.

e. Specify the sampling technique and collection method to be used.

f. Specify the duration of the sample data collection period.

g. Identify geographical location(s) and units located therein best suited to fulfill the requirement.

h. Determine the total density of the candidate equipment item and specify the desired density to be sampled.

i. Determine the availability of financial and personnel resources.

j. Provide a cost analysis of the sample data collection plan.

k. Identify the data flow.

l. Specify the methods of statistical and engineering analysis to be used.

m. Identify the procedure to be used in the conduct of sample data collection (e.g., troop managed and operated, equipment proponent and troop operated, or any other possible combination of operations to include use of contractor assistance and technical representative personnel).

n. Provide for the preparation of draft publications outlining details of the sample data collection program.

o. Specify the method of monitoring sample data collection to insure that stated goals and objectives are attained.

8-1.1.2 logistic Support Analysis Data System (Ref. 4)

The logistic support analysis data system provides a standardized medium for systematic recording, processing, storing, and reporting of data resulting from logistic support analysis. The logistic support analysis record (the system data) identifies and describes support and test equipment; facility requirements; personnel required by skill, type, and number; repair parts;

and quantification of maintenance and operational needs. The data in the record relate to eight general categories:

a. Operation and maintenance requirements

b. Reliability and maintainability characteristics

c. Task analysis summary

d. Maintenance and operator task analysis

e. Support and test equipment or training materiel description and justification

f. Facility description and justification

g. Skill evaluation and justification

h. Supply support requirements.

Details of the logistic support analysis record are contained in par. **5-3.**

8-1.1.3 Depot Maintenance Capability/Capacity and Engineering Data Report (CCEDR) (Ref. 13)

The depot maintenance capability/capacity and engineering data reporting system is an automated data reporting system which provides data defining the capability of CONUS depot activities in terms of their physical resources, human resources, and available support. These data are used in conjunction with other scheduling models and workloading programs to aid in the management of maintenance programs and to provide information for depot maintenance resource management.

Facility information provides data on each building or portion thereof in which depot maintenance is performed. This information includes age, cost, and type of construction; types of installed material handling equipment; lighting, heating, ventilation, air conditioning, and compressed-air facilities; and number and types of nonproduction areas and supporting buildings. Separate information pertaining to outside storage facilities and production and dock areas also is provided.

Information on graphic aids—combined with applicable maps, plots, floor plans, and flow diagrams—provides a detailed view of all depot maintenance facilities.

Information on maintenance equipment provides data for maintenance production equipment and certain hand tools, such as torque and impact wrenches, exceeding a baseline acquisition value.

Information on material handling equipment provides the number and types of mobile material handling equipment required for support of the maintenance operations.

Information on organization skills provides a file of the actual personnel assigned to each work center in depot maintenance.

Information on service contract aids in the development of a required organic capability sufficient to support a specified percent of the mission essential material.

Information on the work center reports those pieces of equipment not peculiar to end item or groups of end items, vital statistics of each work center, labor hours and production data, and man-hour standards, and identifies those pieces of shop equipment that are used specifically in the process of repairing or testing particular types of end items.

8-1.1.4 Commodity Command Standard System (CCSS) (Ref. 5)

The commodity command standard system standardizes logistic functions at the wholesale level and provides an integrated data base for management reporting. The AMC Logistic Program Hardcore Automated (ALPHA) system is an element of the commodity command standard system. The primary subsystems of ALPHA are supply management, maintenance, procurement and production, provisioning, stock control, financial management, and cataloging. The purpose of the system is to provide for an integrated data base that permits consolidation of data files, elimination of redundancies, pinpointing of responsibility/ownership, standardization of data elements, single-set access programs, and a full-range capability.

The key functional features of each of the subsystems are:

a. Supply management provides program data applicable to a commodity; historical data for analysis purposes; automated supply control study/decision data; automatic furnishing of assets and requirements to the applicable command, processing offers of excess stocks, and responding to requirements from other services; supply control study history; automatic computation of standard prices, line item budget computation, computation of mobilization requirements; and inventory stratification.

b. Maintenance provides data in reference to maintenance planning; i.e., man-hours, cost, piece part consumption, and other historical data related to programming; overhaul consumption data used in forecasting quantities of repair parts required to support programmed maintenance; piece part system data with which to compute bit and piece requirements to support depot level maintenance programs, and depot maintenance part requirement lists as requested.

c. Procurement and production provide for automated commitment of funds and generation of procurement work directives, semiautomatic generation of purchase orders, automatic preparation of delivery orders, communication with other agencies by military standard contract administration procedures, internal ordering and control by means of a work order reporting and communication system, and the status of procurement work directives through the preaward phase.

d. Provisioning provides for part number screening and the machine interface from industry to Army engineering efforts through Federal cataloging processes, item entry into the stock number master data record, identification of common use items, item application data, information required for preparation of the test portion of repair part and special tool lists, and automated computation of the initial provisioning requirements based on industry recommendations for initial part requirements, as modified by engineering and commodity management personnel.

e. Stock control provides for precise requisition control, decision making in regard to requisition processing, automatic back order establishment and back order release, mechanical preparation of related supply performance reports, automatic military standard requisition and issue procedure processing and notifications, mechanical surveillance of manual actions to monitor the activities of individuals when final processing within the machine is not possible, station excess reports, inventory details, and establishment of inventory requirements.

f. Financial management provides the processes required for the control of procurement and stock funds; daily ledger maintenance; integration of supply, procurement, and financial processing, based on single data input to the system; automatic fund certification on special requisitions and on procurement actions, flexibility in stock fund control, and automatic billing of the commodity command's customer; and automated generation of all of the related periodic financial reports.

g. Cataloging provides for initial establishment of a record within the stock number master data record, extensive number identification (i.e., part number to a prime stock number or a substitute stock number); collaboration and review prior to the establishment of a line item; and communications between the particular system and major logistic service centers.

8-1.1.5 System-wide Project for Electronic Equipment at Depots, Extended (SPEEDEX) (Ref. 7)

SPEEDEX is the acronym for System-wide Project for Electronic Equipment at Depots, Extended. Except for the word "extended", the acronym is the same as SPEED—a second generation standard computer system used within the U S Army Materiel Command (AMC) depot structure for more than 7 yr.

Officially, the term "extended" means two things. First, it represents the extension of standard automatic data processing (ADP) equipment and standard procedures and computer programs from the 9 original SPEED depots to 11 depots. Letterkenny, Tobyhanna, Sacramento, Sharpe, Pueblo, Red River, Tooele, Anniston, and Lexington comprised the SPEED depots. Added under SPEEDEX were New Cumberland Army Depot and Corpus Christi Army Depot. Second, SPEEDEX means extension of standardized computer systems to all feasible depot functions.

"Extended" means extension of computer and communication capabilities and system design techniques which resulted in the following advantages:

a. Uses third generation computer equipment *b.* Provides for remote processing capabilities

c. Reduces or eliminates card and magnetic tape output

d. Reduces output listings

e. Uses microfilm and micrographics

f. Provides for multiprogramming

g. Provides for increased immediate access to stored data

h. Provides for integrated files

i. Uses materiel receipt control system

j. Uses depot maintenance mathematical scheduling model

k. Provides for integrated system processing

l. Provides for real-time retrieval of operational and management information.

SPEEDEX is an assemblage of standard computers, remote input and output devices, and standardized functional procedures and computer programs designed to accomplish or assist in accomplishing the AMC depot missions of receiving, storing, issuing, and overhauling materiel and providing related support functions on a centralized computer programming and centralized computer program maintenance basis. SPEEDEX covers some 16 logistic and support functions (see Table 8-1) at AMC depots, ranging from receipt and processing of materiel release orders to pay of employees. The equipment configuration at a remote site varies, depending upon such factors as volume and type of input and output, nature of the function being served, and number of systems supported. Remote installation equipment consists of a cathode-ray tube with keyboard, typewriter, card reader, card punch, and line printer.

8-2 DATA COLLECTION AND FLOW PROCESS

In performing its function, maintenance engineering utilizes a wide variety of data throughout a materiel life cycle. Some of the

TABLE 8-1. SPEEDEX SUPPORT FUNCTIONS

Depot supply distribution systems:
- Materiel release order processing
- Storage management
- Ammunition surveillance
- Quality assurance

Depot maintenance and financially oriented systems:
- Maintenance production planning and control
- Expense appropriation management/Army
- Industrial fund for maintenance
- Defense integrated management engineering system
- AMC installation division—stock fund
- Procurement history
- Installation supply accounting
- Facility engineering work management
- Payroll and leave accounting

Depot control systems:
- Calibration
- Management of installation operating equipment
- Accounting **for** in-use nonexpendable property
- Civilian personnel management information system

types of data that are used are described in par. 8-1.1. Other data come from user commands, military specifications and standards, materiel development tests and evaluations, contractor activities, and the scientific community. All of the data are used to influence design, develop a support subsystem, and improve the design and support of deployed materiel.

Some types of data are useful throughout a materiel life cycle, while others have application to some limited number of life cycle phases. An example of the first case is historical experience with similar materiel. Such experience data are useful in new materiel from the conceptual phase through the deployment phase. On the other hand, once production is under way, there would be little use for contractor engineering test data on new materiel; therefore, such data essentially are used last during the development phase.

Fig. 8-1 depicts the sources of several types of data important to maintenance engineering and the timed utilization of the data. The data largely are described in generic terms. For example, maintenance management and depot management data, taken together, are considered to include all data resulting from the operation and support of deployed materiel. Similarly, Army test reports are considered to include all Army test and evaluation reports through the production phase. The figure shows that data from the using command, formal data systems, military specifications and standards, and Army studies are available and are used throughout a materiel life cycle. Army test reports and industry standards are used last during the production phase. The remaining data are used last during the development phase.

Some of the data paths in Fig: 8-1 represent two-way flows. For example, the using command provides requirement and experience data and receives planning data, and the formal data systems provide and receive planning data. Also, since production frequently overlaps deployment, data from deployed materiel may indicate the need for on-line improvements of identical items that are still in the production process.

It may be seen that normally there is an abundance of data during a materiel acquisition program. There is little opportunity for the misuse of data generated by materiel being developed, maintenance engineering analysis data, maintenance evaluation data, engineering test data, etc. The opposite is true in the case of maintenance management and other historical data. Before applying these data, maintenance engineering must insure that the data are both valid and applicable to the case at hand. The data must be derived from deployed materiel that is similar to the materiel being developed, and must represent an overall situation rather than isolated incidents. Moreover, the use and support environment of the deployed materiel must be reasonably representative of the environment anticipated for the new materiel.

8-3 TRADE-OFFS

A trade-off is defined as a quantitative analysis of competing system characteristics and factors to determine the optimum overall combination. Simply stated, it is a comparison of two or more ways of doing something to make a decision. Trade-offs are conducted to some degree of complexity and detail in all phases of materiel acquisition, and are used to obtain, within the operational and performance requirements, an optimum balance among total cost, schedule, and operational effectiveness. Operational effectiveness combines the features of performance, reliability, maintainability, and support.

The primary objectives of trade-offs are to investigate the relative advantages of various concepts or configurations, provide data and background for the feasibility of a program, provide a basic medium, with facts, by which decisions can be made by management, and substantiate or justify a decision.

The trade-off must consider all the factors and not present only those advantageous to some prejudiced viewpoint. The incomplete trade-off study can present shaded facts that will lead to decisions that will be detrimental in terms of life cycle cost when the materiel becomes operational.

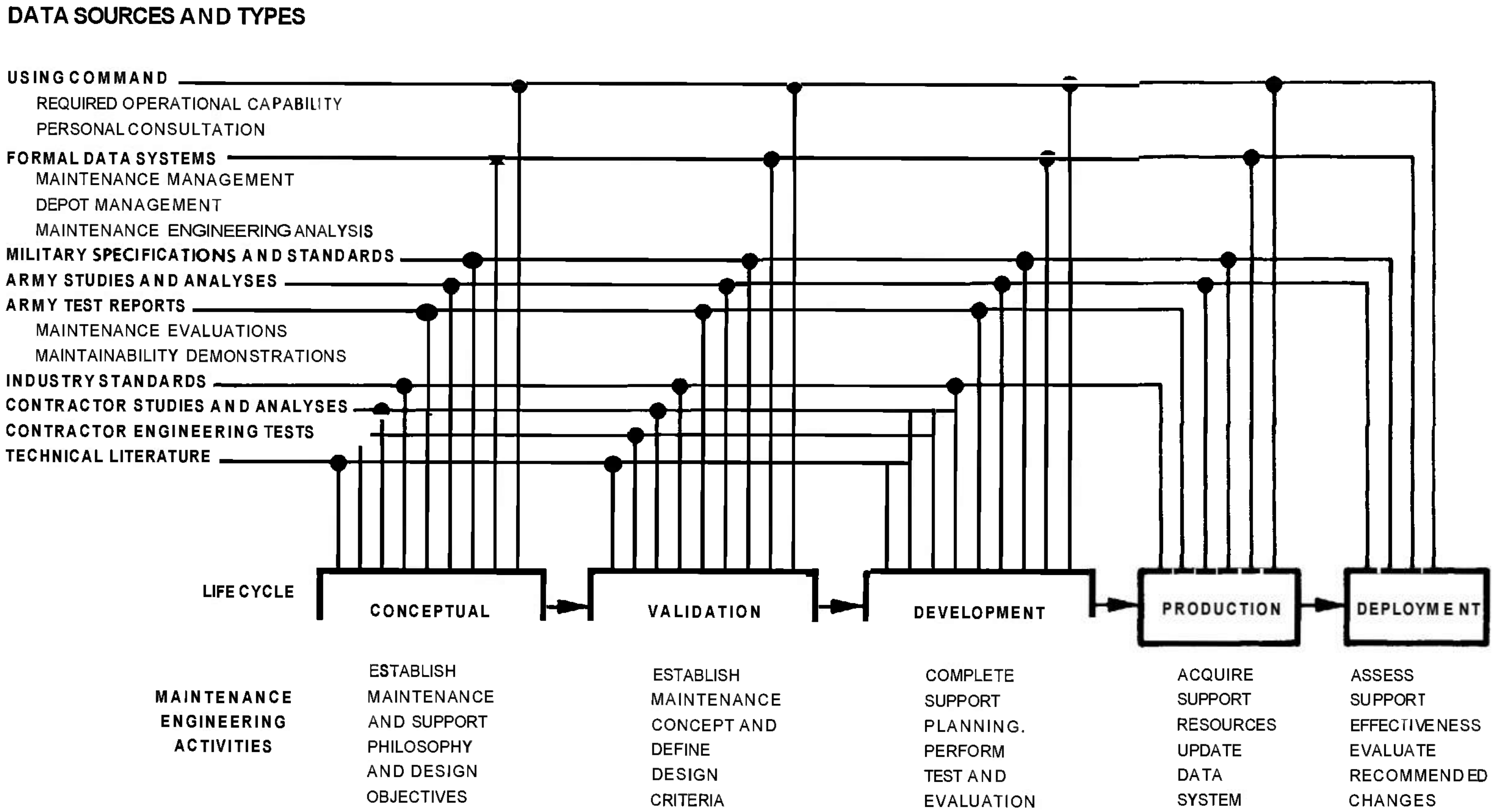


Figure 8-1. Data Utilization by life Cycle Phase

Trade-off categories, procedures, and computer aids are discussed in the following subparagraphs:

a. Categories of Trade-offs. Trade-offs conducted or participated in by maintenance engineering can be classified into three major categories: design philosophy, maintainability design trade-offs, and maintenance support trade-offs.

In each case, the advantages and disadvantages in terms of effect on operational effectiveness and life cycle cost are considered. Table 8-2 summarizes the types of trade-offs, the hardware level considered, the phase of the life cycle, the input requirements, and the output of each category trade-off.

Trade-offs usually are conducted between maintenance and support parameters, with operational parameters remaining constant. This is not to say that operational parameters are never traded off. Range, payload, operational availability, etc., are subject to trade-offs during the conceptual phase and to a lesser degree in the validation phase. After that time, they become established as firm operational requirements that must be satisfied by subsequent maintenance and support parameter trade-off candidates.

TABLE 8-2. TRADE-OFF SUMMARY

Types of Trade-off	Level and Phase	Example	Input Requirements	output
Design philosophy	Top-level system Conceptual phase Basically systems conducted trade-off impacted with maintenance considerations Conducted prior to maintainability design trade-offs	Conducted to determine type of design in terms of category or class: Analog vs digital Electromechanical vs hydraulic Manual vs automatic	Equipment locations and quantities Equipment environment and usage rates Reliability information Constraints from requirement statements Results of higher level analyses or trade-offs Previous decisions Cost data	Selection of subsystem/end item types Preliminary maintenance concept
Maintainability design	Lower level subsystem Validation and development phases Conducted prior to final design	Exception trade-offs: conducted when exception to a previously established maintainability requirement is proposed in design Optimization trade-offs: conducted for each system/subsystem to select optimum configuration: Fault isolation method Maintenance concept	As previously listed	Selection of optimum configuration for subsystem/end item, etc., in terms of design features Design concept Maintenance concept
Maintenance support	Detailed level Development phase Conducted after design is firm	Conducted to determine optimization of support for system rather than hardware design	As previously listed	Maintenance concept Maintenance plan

The types of maintenance parameters that are traded off are diagnostics, mechanical and electronic packaging, reliability, accessibility, etc. A maintenance parameter trade-off normally involves a consideration of support parameters, because maintenance parameter candidates usually impact support resources, and it is necessary to determine the impact and convert the support resources into costs. In order to make a decision, these costs are considered along with the research and development and initial acquisition costs generated by each maintenance parameter candidate.

Unlike maintenance parameter trade-offs, support parameter trade-offs can be conducted somewhat independently. Given operational and deployment requirements and a fixed materiel design, trade-offs can be conducted among personnel, repair parts, publications, and other support resource requirements associated with various support candidates. In most cases, these trade-offs are used to optimize decisions reached during maintenance parameter trade-offs. Therefore, it is the maintenance parameter trade-offs that have the most significant impact on support resource requirements and consequently on life cycle costs.

b. Trade-off Procedure. Trade-offs normally require the participation of several functional disciplines for appreciable periods of time. To make most efficient use of the personnel resources involved, it is prudent to follow a systematic procedure such as the one outlined in the subparagraphs that follow.

The major steps of the trade-off procedure are to establish integration and control, gather constraints and identify system requirements, select candidates, compile data (quantitative and qualitative), document and calculate, analyze results, produce reports, and obtain approval.

(1) *Establish Integration and Control.* This step establishes the overall approach to the trade-off, and the responsibility and scheduling to insure effective and timely results. Since the required data are generated or developed from various sources (finance, engineering, procurement, maintenance engineering, reliability, maintainability, etc.), it is essential to establish an authoritative source (task leader) for coordination of the effort.

The major tasks are to identify participants and responsibility, establish data sources and requirements, establish dimensions for data, and schedule inputs and outputs.

The definition of purpose, approach, and data requirements is an essential building block in the conduct of a trade-off. Early definition insures that data inputs are usable as submitted, correct, and in consonance with other data inputs. A common basis must be established that will allow rapid comparison of advantages and disadvantages. The data base most easily understood is the dollar, and this data base has the advantage of establishing a cost-effectiveness comparison.

(2) *Gather Constraints and Identify System Requirements.* The constraints imposed on the system pertaining to deployment, utilization, equipment quantities, acquisition or support cost, maintenance concept, maintenance resources, maintenance time, availability, etc., should be identified at this time. The constraints may result in the elimination of some tentative candidates due to noncompliance. This elimination avoids extensive and often meaningless trade-off effort.

The requirement for trade-offs is limited by the depth and definitiveness of the system specification. For example, if the specification states that an electromechanical system has fault isolation by built-in test equipment to a discard-at-failure maintenance plug-in module, a module cost of not more than $50, a mean time to repair of 15 min, and a mean time between failures of 700 hr, the following trade-offs are eliminated: hydraulic versus electromechanical, repair versus throwaway, optimum level of repair, external versus built-in test equipment, and a compromise between mean time to repair and mean time between failures to achieve a stated availability.

(3) *Select Candidates.* Based upon prior identification of the system constraints and data bank information, the feasible candidates for either a design philosophy trade-off, maintainability trade-off, or maintenance support trade-off may be identified. An adequate description of each candidate is required to insure that all participants in the trade-off study can develop their input data adequately and on a common understanding of candidate configuration. The baseline maintenance concept,

reliability data, hardware cost, utilization concepts, and manufacturing and production techniques are types of information required for general dissemination. For example, the reliability analyst requires a system description from the system or design engineer to perform failure rate predictions, the maintainability analyst requires the failure rates to perform apportionments and predictions, the maintenance analyst requires the failure rates to determine repair part requirements, etc. Each candidate must be analyzed to assure that it meets or exceeds the operational requirements and system constraints.

(4) *Compile Data (Quantitative and Qualitative).* The participants who are responsible for supplying data inputs into the trade-off must compile quantitative and qualitative data as required to satisfy the data base requirements. The compilation of data is not an independent function. There is an interflow of data among participants, and this effort must be scheduled to insure the availability of all data from all participants at the scheduled time.

(5) *Document and Tabulate.* The data developed and submitted by the participants in the trade-off should be documented and tabulated in a clear, concise, and orderly manner. The cost categories previously identified collectively include all costs that would affect a cost trade-off decision. These categories are combined under the major classification of acquisition, installation, operational and maintenance, or support costs. Availability of cost data on the baseline system may be restricted or nonexistent. In this case, the candidates may be assigned best estimate cost deltas in relationship to each other.

(6) *Analyze Results.* The results of the trade-off should be analyzed to determine the cost versus system effectiveness relationship or availability per dollar cost expenditure. Total cost utilized alone, unless all other factors are equal, should not be the firm basis for system selection. The increase in reliability, decrease in maintenance time, future growth potential, and performance are areas in which large improvement may be recognized in relation to slight increase in total cost. In addition, the analyst should perform parametric (or sensitivity) analysis, identify additional data requirements, and evaluate compliance with requirements.

Variance in data may impact the results of the study. A parametric analysis should be conducted which varies such factors as equipment quantities and range of mean time between failures to facilitate the rapid comparison of effects of changes on total system cost or concepts. The variance and parameter selected should be based on foreseeable realistic equipment demands or trends.

The requirement for additional data may result when trade-off results show no significant difference among candidates. In these cases, the data and information should be reexamined to determine if a more comprehensive analysis of these candidates can be conducted.

The candidates should be evaluated in relationship to their degree of compliance with the requirements. In this respect, the analyst should consider the cost/system effectiveness relationship with respect to strict compliance with or exceeding the stated requirements. Risks should be considered and identified.

(7) *Produce Report and Obtain Approval.* The report presented to management for approval should be in a standard format. The format should present a summary of the report and, in addition, provide the detailed background or backup data used in the preparation for further analysis, if required.

Concurrencelby management with the recommendations of the trade-off will result in the incorporation or implementation of the hardware design philosophy, maintainability design feature, or maintenance support concept for the system. The trade-off procedure is an iterative process, and trade-offs are updated as additional data become available; however, trade-offs should be considered final when they have resulted in final decisions and implementation of design or support concepts to such an extent that cost or schedule would be affected detrimentally by reversal of decisions.

c. Computer Aids. The development of computer programs should be considered to aid in the conduct of trade-offs. The data used in trade-offs during equipment concept, validation, or development may comprise constantly changing parameters. The effect a change in one variable has on total system cost or on the performance characteristics may be negligible, or it may be quite significant. In the case of a reliability (failure rate) change, the impact has a mushrooming effect. The operational and maintenance parameters such as availability and mean corrective time, and the support parameters (due to impact on support features such as repair part quantities, personnel requirements, or maintenance labor) are all affected by a reliability change.

The need for computer program development depends upon the time frame of the program, the magnitude and complexity of the equipment, the magnitude of trade-off requirements, the detail of data to be available, and the program budget.

Basically, computer models for trade-offs are divided into two major categories: computation and simulation.

The computational model is developed to use the computer capability to perform the extensive computations involved in the procedures for prediction, performance, evaluation, and total life cycle costing. This assures that exactly the same computational procedure is used for each candidate and eliminates computational errors.

The simulation model is developed to perform a simulation of system operation over its entire life cycle. From the simulation, statistics are developed that isolate critical support, reliability, and maintainability elements and identify profitable areas of improvement. The simulation also provides quantitative output information suitable for direct input to system and cost-effectiveness models.

8-3.1 USES OF STATISTICAL PROCEDURES TO EVALUATE TRADE-OFF ALTERNATIVES

Acceptable trade-off candidates must meet or exceed materiel operational requirements throughout the materiel life cycle. Since the normal materiel life cycle is considered to be 5 to 10 yr or more, it is desirable to examine the effects of combinations of maintenance and support parameters on materiel availability over a period of years to determine if the combinations are suitable candidates. There are two basic ways to accomplish the long-range estimate. One is to use reliability and maintainability, and other data in a deterministic manner. The other is to use these data in a manner that permits them to reflect their results in a statistical manner.

8-3.1.1 Deterministic Approach

In the deterministic approach, the analyst accomplishes all calculations with average Values. For example, if an item being analyzed has a mean time between failures of 6 months and a mean time to repair of 2 hr, the deterministic approach shows that the item will be down for maintenance for **2** hr, every 6 months. If there are 100 items, it is estimated that there will be 200 failures per yr, or approximately 17 per month, or roughly one failure every other day, with **2** hr of maintenance for each failure. This approach makes for an easy calculation; however, it is almost a certainty that the failures will not occur according to the predicted schedule. Rather, they will occur in a random manner—five one day, none for the next **3** days, one the next day, etc.—to provide an average of one failure every other day over a long period of time.

8-3.1.2 Statistical Approach

To plan effective economical materiel support, maintenance engineering must know the probable distributions of failures by hour, day, etc., throughout the materiel life cycle. Such a distribution permits an analysis of the peaks and valleys in maintenance resource requirement demands, and a determination of the effect of various quantities of resources on materiel availability. Normally, the analysis demonstrates that resources should be provided to support a maintenance workload less than the largest of the peak demands and greater than that indicated by the average failure rate.

Probable materiel failure rate distributions can be calculated manually with the assistance of random number tables, but the task is tedious and time consuming. **A** method more commonly used to obtain such statistical data is dynamic simulation. This process involves the use of a computer and one of several computer languages. Once the program is written for a particular materiel system, operational and support statistical data spanning years of simulated operations may be obtained in a matter of minutes.

A dynamic simulation model can be constructed to accommodate any level of detail warranted by the analysis to be made and the data available. A typical model and program will reflect the planned number, types, and locations of both the deployed materiel and the support resources. Failure rates and corrective maintenance time distributions for the materiel and support equipment are entered, as well as preventive maintenance times and schedules. The materiel is operated according to a prescribed scenario, fails randomly rather than deterministically, and is repaired in varying lengths of time. The model and computer program contain logic that permits a maintenance resource to be used only when it is not engaged in some other activity, and according to predetermined priorities. Preventive maintenance also is accomplished according to predetermined priorities. The time of each activity is recorded in a manner that permits conversion to calendar time.

A typical computer printout of a program run will show when materiel was available, when it was down for maintenance, how long it waited for maintenance, etc. It will also show when tools, test equipment, facilities, personnel, etc., by individual item or person, were being used, what they were engaged in, when they were idle, etc. In short, a model can be constructed and programmed to provide predicted data for virtually any data that may be acquired from the operation and maintenance of a deployed system.

8-3.1.3 Statistical Example

A simulation model for an Army missile system will be described to demonstrate the advantages of dynamic simulation. The basic flow of the model is shown in Fig. 8-2. The purpose of the model is to determine the operational effectiveness to be realized from various combinations of maintenance and support parameters.

The inputs to the model were:

a. Countdown frequency

b. Countdown type distribution

c. Probability of countdown success

d. Failure impact on system availability

e. Percent of failures repaired at site

f. Supply and administrative times

g. Float turnaround time

h. Mean active repair time

i. Repair time distribution

j. Mean active replace time

k. Replace time distribution.

The model in Fig. 8-2 provides for two types of countdowns. The input data provide for random selection of the type and for random successes and failures. If there is a failure, system availability is impaired, and a repair or replace maintenance action is generated. Replace actions are further divided into float and nonfloat replacements. A record is kept of all maintenance, supply, and administrative time required to return the failed item to service.

Typical outputs of the model are:

a. Availability

b. Percent of target coverage by missile

c. Total failures during simulated period

d. Number of failures of each end item

e. Float demand by end item

f. Float demand when no float is available

g. Percent of time no working float is available

h. Mean downtime due to unavailability of float

i. Mean repair time without supply and administrative time by end item

j. Mean repair time with supply and administrative time by end item

k. Mean replace time without supply and administrative time by end item

l. Mean replace time with supply and administrative time by end item.

It will be noted that models such as the one described are concerned only with operational effectiveness. The models can be built and programmed to provide costs for each alternative, or costs can be calculated separately.

8-3.1.4 Engineering Judgment Approach

The systematic application of the judgment of a group of experienced personnel for making a selection from alternate problem solutions is

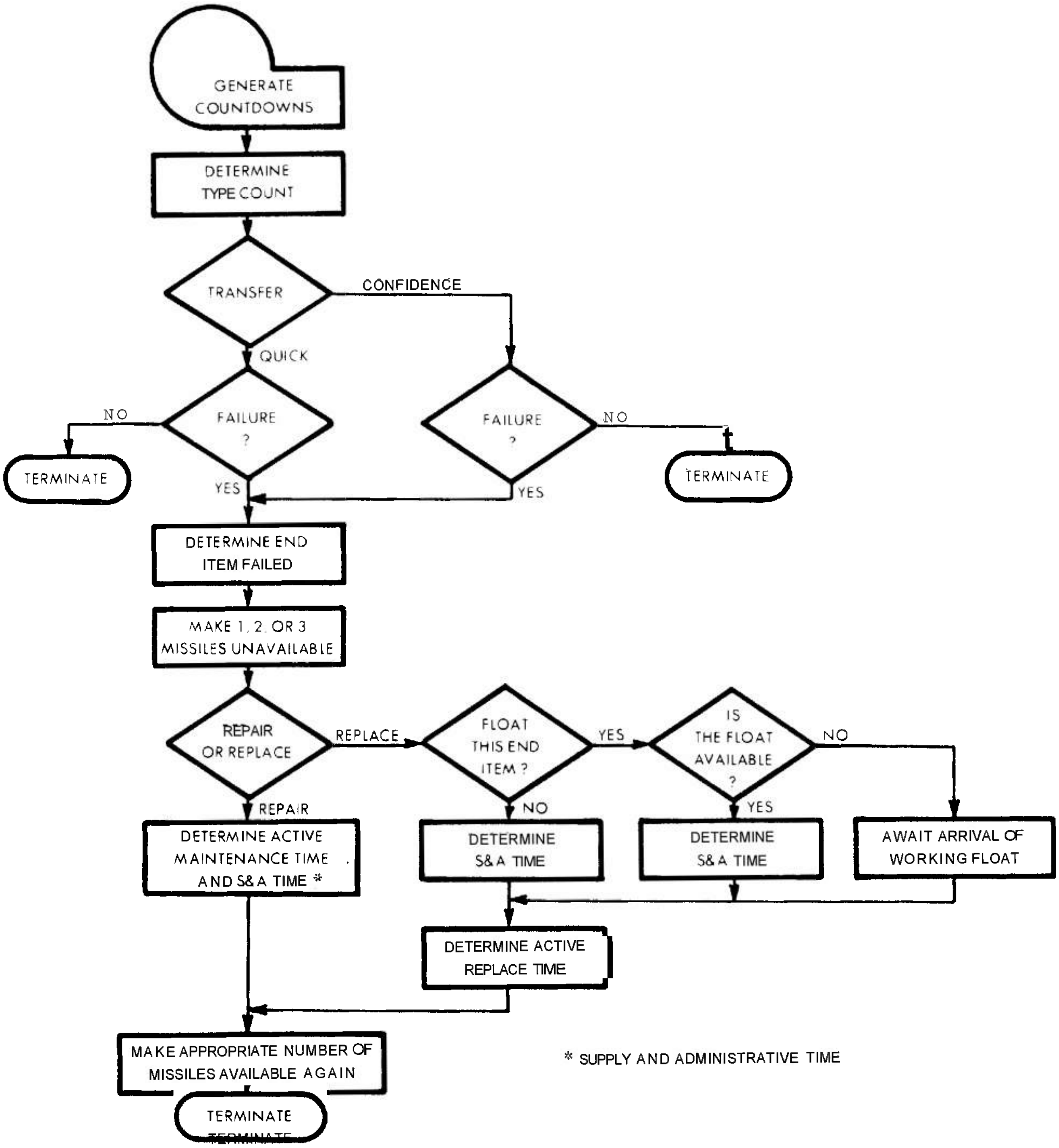


Figure 8-2. Simulation Model Basic Flow

an elementary application of statistical procedures. In such cases, years of experience data are manipulated mentally, and applicable statistics such as an estimated mean or evaluation rating result. This approach to decision making is rapid and economical. The accuracy of the approach is a function of the experience and objectivity of the participating personnel.

In this approach, the most significant parameters involved in a decision are selected and weighted in terms of importance to the final solution. The degree to which each parameter satisfies solution requirements is then established with regard to some established scale, this value is multiplied by the weight factor, and resulting values are summed. The solution with the most favorable sum is selected.

Table **8-3** contains an engineering judgment type of trade-off. The purpose of the trade-off was to select the most effective quick-access splice for an Army missile. A baseline configuration had been established during the validation phase, but further study revealed that the baseline did not meet established time requirements for missile mating operations.

TABLE 8-3. ENGINEERING JUDGMENT TRADE-OFF

1 OBJECTIVE

To select a missile splice method.

2. ALTERNATIVES

a. Spline splice (baseline)
b. Internal interdigitated teeth ring assembly (alternative 1)
c. External interdigitated teeth ring assembly (alternative **2)**
d. Internal expansion ring (alternative **3)**
e. Vee band (alternative **4).**

3. EVALUATION PARAMETERS

Mating time is a prime consideration. The weight of the missile is critical, as it affects range; therefore, splice weight is also critical. Other factors to be considered are cost, design margin, technical risk, ground support equipment, logistics, and human factors.

4. WEIGHT FACTORS

Weight factors are established for the evaluation parameters as shown in the trade-off matrix (at end of table). These factors are assigned based on engineering judgment and the mutual agreement **of** trade-off participants. Participants represent the functions of system engineering, reliability, maintainability, maintenance engineering, support elements, finance, human factors, and manufacturing. The term "logistics" in the trade-off matrix represents both maintenance engineering and the support elements. A weight of **10** is assigned to the time and weight parameters. Lesser weights, as shown, are assigned to the other parameters.

5. MATRIX

The trade-off matrix shows measurement units for evaluation parameters, when applicable. The "Weight Factor" column contains quantitative, qualitative, and weight factor lines. The quantitative lines contain estimated values, the qualitative lines contain scoring values from 0 through **10,** and the weight factor lines contain the product of the weight factor and the scoring value. The qualitative values are assigned based on the degree to which the parameter satisfies the requirement, with **10** being the highest possible score. A 0 in any column indicates unacceptability of the candidate with regard to the indicated parameter. Therefore, the candidate total is listed as 0, regardless of the values generated by it and the other parameters.

TABLE 8-3. ENGINEERING JUDGMENT TRADE-OFF (Cont'd)

6. QUANTITATIVE AND QUALITATIVE VALUES

Quantitative values for time, weight, cost, and design margin were developed as follows:

a. Time. Times were derived from recorded data and analysis. The time for the baseline was obtained from tests that had been conducted on an existing, similar configuration. Time line analysis was used for the other candidates. Alternative **3** was abandoned at this point in the trade-off since it was determined that it was unsatisfactory with regard to time. However, prior to this decision, certain other alternative **3** data had been generated, and are included in the matrix.

b. Weight. Weights were calculated with dimensional and material data obtained from conceptual drawings.

c. *Cost.* Costs were based on estimated manufacturing and material costs.

d. Design Margin. Design margin refers to the design safety factor and was derived from an analysis of material and conceptual design data.

Qualitative values for each parameter were developed by appropriate functional groups. For example, human factors, maintainability, and maintenance engineering assigned a value for time, maintenance engineering and the support elements assigned a factor for logistics, etc. Each person participating in the evaluation of a parameter assigned a qualitative value between 0 and **10,** and the sum of the values was averaged and entered into the matrix.

7. SUMMARY

Weight factors were multiplied by scoring values, and the results were summed as shown in the trade-off matrix. Alternative **3** had been eliminated previously because of excessive time requirements. The baseline alternative was eliminated for the same reason. Alternative **4** was eliminated because of excessive time requirements and an unacceptable design margin. The study, therefore, results in the selection of alternative **1** on the basis of a total qualitative factor of **210** as compared to **176** for alternative **2.**

TRADE-OFF MATRIX

Evaluation Parameters	Weight Factor	Alternative Candidates				
		Baseline	1	2	3	4
Time, min	Quan	**3** to 5	0.5 to **1**	0.5 to 1	---	**2** to **4**
	Qual	0	5.0	5.0	---	0
	10	0	50	50	---	0
Weight, lb	Quan	**20.3**	**17.3**	**45.6**	55.0	**37.8**
	Qual	**4.9**	5.8	**2.2**	**1.8**	**2.6**
	10	**49**	**58**	**22**	**18**	**26**

TABLE 8-3. ENGINEERING JUDGMENT TRADE-OFF (Cont'd)

TRADE-OFF MATRIX (Cont'd)

Evaluation Parameters	Weight Factor	Alternative Candidates: Baseline	1	2	3	4
Cost, $/splice	Quan	1170	1799	1889	1323	1626
	Qual	8.5	5.5	5.2	7.6	6.2
	5	43	28	26	38	31
Design margin	Quan	0.23	0.39	0.15	---	0
	Qual	1.23	1.39	1:15	---	0
	4	5	6	5	---	0
Technical risk	Qual	3.0	1.0	2.0	0	3.0
	5	15	5	lo	---	15
GSE considerations	Qual	2.0	5.0	5.0	3.0	4.0
	3	6	15	15	9	12
Logistics	Qual	5.0	7.0	8.0	---	9.0
	3	15	21	24	---	27
Human factors	Qual	4.0	9.0	8.0	---	6.0
	3	12	27	24	---	18
Totals		0	210	176	---	0

The following basic steps were followed in conducting the trade-off:

a. Identify the alternatives.

b. Determine evaluation parameters.

c. Determine weight factor assignment.

d. Develop matrix.

e. Establish quantitative **and** qualitative values.

f. Summarize results.

The example trade-off considered cost as an evaluation parameter; therefore, it is, in effect, a cost-effectiveness trade-off. This type of trade-off is particularly valuable when only conceptual data are available for many candidates, and there is an urgent requirement to narrow the field and concentrate on a limited number of candidates.

8-3.2 TRADE-OFFS BASED ON DATA ANALYSIS

The validity of a trade-off depends upon two basic factors: identification of all activities and resources impacted by each of the trade-off candidates, and the assignment of proper quantitative values and qualitative considerations to the impacted parameters. Identification of the impacted parameters is normally straightforward. Essentially, a consideration **of** design, development, **and** acquisition requirements will identify all significant cost generators involved with the basic hardware. Application of the materiel support plan to the planned deployment scenario then will assist in identifying significant support resource requirements. When new support and test equipment is required, applicable design, development, and acquisition costs again enter the picture.

The real trade-off problem concerns the second factor, which is the assignment of quantitative values and qualitative considerations, particularly quantitative values. For example, what are the reliabilities and mean times to repair of the candidates, what are the development and acquisition costs, what are the repair part costs, what is the operational availability, etc.? Many of these and other values that must be calculated or estimated for new materiel are based on a combination of performance data accumulated in data systems for existing materiel, and on predictions. For example, the predicted reliability of materiel in the conceptual phase is based on performance data accumulated from other like materiel and components, and from design analysis. After the new materiel is deployed, the predicted reliability of a modification is based on the previously identified factors, plus data acquired during the development and deployment of the new materiel. Similar statements apply to the derivation of maintenance times and costs.

Qualitative considerations frequently do not enter a trade-off decision. However, when the difference in costs is not significant, it is necessary to consider qualitative factors. An example is a situation in which candidate A is slightly more costly than candidate B, but the latter involves some state-of-the-art development. **A** logical choice would be candidate **A,** because any development problems with candidate B undoubtedly would result in a significant cost increase of the trade-off estimate. Other examples of qualitative considerations are contained in par. 8-3.2.2.

Two examples of typical trade-offs are discussed in the paragraphs that follow to demonstrate the complexity of trade-offs, parameters that must be considered, parameter interfaces, and how quantitative values are assigned to the parameters. Some of the cost factors, such as labor rates and supply management costs used in the trade-offs, are not current, but this does not negate the purpose for which the examples are presented.

8-3.2.1 Discard-at-Failure Maintenance or Repair Trade-off

Table 8-4 presents a trade-off that was conducted to determine whether it is more economical to discard or to repair certain failed printed circuit cards in end items that are a part of an Army missile weapon system. The trade-off is conducted in two ways: method I is a conventional trade-off, and method II is a parametric trade-off.

TABLE 8-4. DISCARD-AT-FAILURE MAINTENANCE OR REPAIR TRADE-OFF

PURPOSE

The purpose of this study is to determine whether the maintenance concept for printed circuit cards should be discard-at-failure maintenance or depot repair.

APPROACH

This study was conducted in the following manner:

1. The failure rates and operating times of the printed circuit cards were used to determine the failures for a 5-yr period. As an example, the current driver card has a predicted failure rate of 181.420 per 10^6 hr (see Chart II), which gives a mean time between failures of 5512 hr. The estimated operating time of the 106 end items considered is 769,600 hr over a 5-yr period. Dividing the mean time between failures into the estimated operating time gives 139.6 failures, which is the number of predicted failures that this card will experience. (NOTE: Fractions of card failures one-half or greater were rounded off to the next whole number.) The product of the number of failures (140) and the cost of the card ($435.00) is the discard cost for that card for 5 yr. This was repeated for each of the 19 cards.

TABLE 8-4. DISCARD-AT-FAILURE MAINTENANCE OR REPAIR TRADE-OFF (Cont'd)

2. Repair cost considerations were as follows:
   a. Cost of replacement parts
   b. Cost of depot labor and overhead
   c. Cost of transportation
   d. Cost of publications
   e. Cost of depot tooling
   f. Cost of entering and maintaining line item piece parts in the Army system
   g. Cost of on-vehicle materiel and system repair parts were considered from the standpoint of the present system of supply stockage; this results in the same initial costs for repair parts in either concept.

   Two methods were used to determine which philosophy—discard at failure or repair—was to be followed:

   Method I. The total cost of failures was determined by finding the predicted failures of each card, multiplying this by the cost of that card, and summing the products. This was compared to the sum of items 2*a* through 2*f*, which is the repair cost.

   Method II. A math model was derived and the graph (Fig. I) was formulated (using data from Method I). This determines the maximum average cost of the printed circuit cards that could be justifiably discarded for various numbers of failures incurred. The average cost of the 19 cards considered in this trade-off versus the total number of failures is then compared against the curve. Alternatively, dividing the total failures into the total cost of replacement cards yields the average cost per failure.

ASSUMPTIONS

1. The one-hundred and six (106) end items in which the cards are installed will operate a total of 769,600 hr over a 5-yr period.
2. Failure rate data are based on current project reliability data.
3. Depot labor and overhead costs are estimated at $7 per hr and average repair time for a printed circuit card is 4 hr.
4. Estimated cost of repair parts is assumed to be 25 percent of the replacement cost.
5. Printed circuit cards will be returned to depot in quantities of 10 cards per package at a cost of $100 per package. This includes the cost of shipping, packaging, labor, etc.
6. Depot tooling would consist of a manual card tester and a close-tolerance card tester at a cost of $77,209 and $50,393, respectively, based upon the current design concept. A close-tolerance tester is needed for six cards; i.e., negative bit generator, programmable power supply, −65V power supply, comparator, and operational amplifiers A and B. The manual card tester is used for the other printed circuit cards. This study considers the cost of repair of these two groups of cards separately.
7. Repair capabilities exist at depot only.
8. Cost to enter a line item in the Army Supply System is $2,526.46. The cost of maintaining each line item is $1,394 per yr.

TABLE 8-4. DISCARD-AT-FAILURE MAINTENANCE OR REPAIR TRADE-OFF (Cont'd)

9. When repair of these cards is considered, approximately 34 new line items will be entered into the Army supply system.
10. The publication effort for depot manuals is 32 hr to write procedures for each printed circuit card at $12 per hr.

RESULTS

Method I. The results of the trade-off using Method I are summarized in Chart I and indicate that the predicted cost to repair is $431,872 for that group of cards using the manual card tester and $251,740 for the group using the close-tolerance card tester. The predicted cost for discard at failure maintenance is $390,022 for the manual test group and $238,804 for the other group. This provides a net savings of $41,850 for the first group and $12,936 for the second group over a 5-yr period if discard-at-failure maintenance is adopted.

RECOMMENDATION

Method I indicates that it is more economical to adopt the discard-at-failure maintenance concept rather than repair. Method II also indicates that discard is justified. Therefore, it is recommended that the discard at failure maintenance concept be adopted. The advantages of adopting this concept are:

1. Training of personnel in the repair of the printed circuit cards is eliminated.
2. Documentation requirements are reduced.
3. Record-keeping requirements are reduced because the items are expendable.
4. Fewer line items are retained in supply.

CHART I
METHOD I COSTS

	REPAIR		DISCARD	
	(a)	(b)	(a)	(b)
1. Depot tooling	$ 77,209	$ 50,393		
2. Depot labor and overhead	31,864	18,704		
3. Transportation	11,380	6,680		
4. Publications	4,992	2,304		
5. Line item entry	208,922.12	113,957.52		
6. Repair materials	97,505	59,701	$390,022	$238,804
TOTALS	$431,872.12	$251,739.52	$390,022"	$238,804*

(a) Costs associated with manual card test group.
(b) Costs associated with close-tolerance card test group.
* Chart II shows the data used to determine the cost.

TABLE 8-4. DISCARD-AT-FAILURE MAINTENANCE OR REPAIR TRADE-OFF (Cont'd)

METHOD I COST CALCULATIONS

The number of failed cards in the 5-yr period is 1,806 (from Chart 11).

1. Depot Tooling
   (a) $77,209 Manual card tester (Option a) (13 cards)
   (b) $50,393 Close-tolerance card tester (Option b) (6 cards)

CHART II
PRINTED CIRCUIT CARD FAILURE AND COST DATA

		Cards per End Item	Failures per 10^6 Hr	*MTBF*, Hr per Card	Failures in 5 Yr	Cost per Card, $	Total Cost Failed Cards, $
(a)	Current Driver	6	181.420	5,512	140	435	60,900
	XZ Torquer	2	177.226	5,642	136	436	59,296
	HEFU Timer	1	161.186	6,204	124	184	22,816
	Servo Amp	1	144.781	6,906	111	401	44,511
	Y Torquer	1	144.072	6,940	111	355	39,405
	+24 VPS	4	69.131	14,465	53	577	30,581
	Mod/Demod	1	48.926	20,439	38	488	18,544
	Telephone Amp	2	46.768	21,382	36	355	12,780
	FAC Monitor	1	39.324	25,429	30	302	9,060
	Reed Relay	3	23.265	42,983	18	404	7,272
	AC/DC Self-Test	1	64.708	15,454	50	226	11,300
	Voltage Sensor	1	57.839	17,289	45	257	11,565
	Relay	32	319.481	3,130	246	252	61,992
					1,138	$4,672	$390,022

Average cost of cards considered $\frac{\$4,672}{13} = \$359$

		Cards per End Item	Failures per 10^6 Hr	*MTBF*, Hr per Card	Failures in 5 Yr	Cost per Card, $	Total Cost Failed Cards, $
(b)	−65 VPS	1	184.982	5,405	142	258	36,636
	Op. Amp (A)	2	177.695	5,627	137	413	56,581
	Comparator	1	171.815	5,820	132	331	43,692
	Neg. Bit Gen.	2	129.151	7,742	99	551	54,549
	Op. Amp (B)	1	108.748	9,195	84	413	34,692
	Prog. P.S.	1	96.263	10,388	74	171	12,654
					668	$2,137	$238,804

Average cost of cards considered $\frac{\$2,137}{6} = \$356$

TABLE 8-4. DISCARD-AT-FAILURE MAINTENANCE OR REPAIR TRADE-OFF (Cont'd)

2. Depot Labor and Overhead

Depot costs = Number of failed cards × hourly rate (in dollars) × average hours to repair

(a) 1,138 × 7.00 × 4 = $31,864

(b) 668 × 7.00 × 4 = $18,704

3. Transportation Cost

$$\text{Transportation cost} = \text{Number of failed cards} \times \frac{1}{\text{Number of cards per package}} \times \text{cost (in dollars) per package.}$$

(a) $1{,}138 \times \frac{1}{10} \times 100 = \$11{,}380$

(b) $668 \times \frac{1}{10} \times 100 = \$\ 6{,}680$

4. Publications Cost

Publication cost = Number of card types × publication hours per card × hourly rate (in dollars)

(a) 13 × 32 × 12 = $4,992

(b) 6 × 32 × 12 = $2,304

Total $7,296

5. Cost to Enter and Maintain Line Item

Number of line items [line item entry cost in dollars + (service life years × annual line item management cost in dollars)] = cost to enter and maintain line items.

(a) 22 [2,526.46 + (5 × 1,394)] = $208,922.12

(b) 12 [2,526.46 + (5 × 1,394)] = $113,957.52

Total $322,879.64

6. Cost of Materials to Repair Cards

Percent of card cost per repair × total cost (in dollars) of failed cards = cost of materials.

(a) 0.25 × 390,022 = $97,505

(b) 0.25 × 238,804 = $59,701

Method II. Method II considers all parameters noted in Method I. Based on failure rates, the average cost of the cards is determined. If the average cost of the cards is **$388.62** or less with 1,806 failures, discard at failure maintenance is justified. The average cost of the printed circuit cards considered (19 cards) is $358.36. This indicates that discard at failure maintenance is justified.

TABLE 8-4. DISCARD-AT-FAILURE MAINTENANCE OR REPAIR TRADE-OFF (Cont'd)

METHOD II LOGIC AND CALCULATIONS

Discard is more economical than repair whenever the cost of repair is greater than or equal to the cost of discard at failure (Cost of repair ≥ cost of discard at failure).

By the use of a mathematical model, the break-over point can be calculated where the average cost per card is such that cost of repair would be exactly equal to the cost of discard at failure.

A. Cost of repair = tooling + labor and overhead + transportation + publications + line item entry + repair materials = XY

where

Y = total number of card failures in 5 yr = 1,806 (from Chart 11)

X = average cost of the cards

B. Then XY = 1,806X = average cost of replacement of those cards in 5 yr, which is also equal to average cost of discard at failure maintenance.

Setting Eq. A = Eq. B, the break-over value (where discard is more economical than repair) of X will be calculated.

C. $$127{,}602 + (7)(4)Y + \frac{100Y}{10} + 7{,}296 + 322{,}879.64 + 0.25XY = XY$$

$$457{,}777.64 + (38)(Y) + 0.25XY = XY$$

$$457{,}777.64 + 38Y = XY - 0.25XY$$

$$457{,}777.64 + 38Y = 0.75XY$$

$$\frac{457{,}777.64}{Y} + 38 = 0.75X$$

$$\frac{457{,}777.64}{1{,}806} + 38 = 0.75X$$

$$253.47 + 38 = 0.75X$$

$$\frac{291.47}{0.75} = X = 388.62$$

Various values for X and Y are graphically presented in Fig. I, with the above calculated values (X = 389, Y = 1,806) indicated with dashed lines.

From the curve, the maximum average cost of cards may be determined for any number of predicted failures in the 5-yr period.

For example, if 1,600 cards were to fail in 5 yr, the curve shows that the break-over point would be approximately $400.00. A graph with a larger scale would permit a more accurate determination of the point by which calculation is $432.14.

The actual predicted number of failures (1,806) falls at a point on the curve which has a large negative slope, where large changes in the number of predicted failures result in relatively small changes in the number of dollars on the X-axis (abscissa).

TABLE 8-4. DISCARD-AT-FAILURE MAINTENANCE OR REPAIR TRADE-OFF (Cont'd)

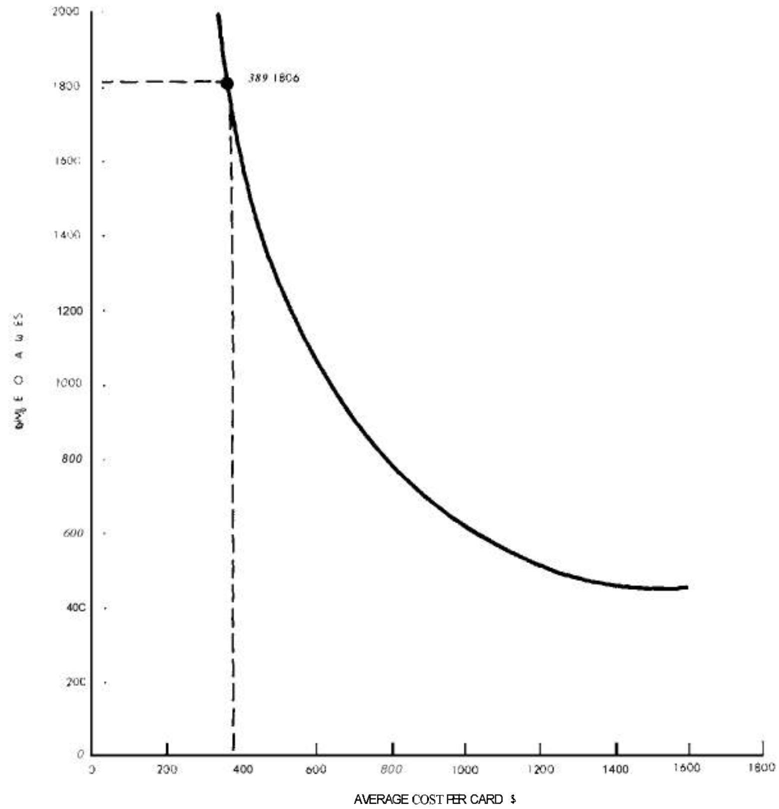


FIGURE I. REPAIR VS DISCARD-AT-FAILURE MAINTENANCE COSTS

The method II approach is very useful in studying the impact of a varying maintenance parameter on life cycle costs. In the example, the parameter that can be varied is reliability. It is possible to restructure the equation to study the effect of other varying parameters such as mean time to repair. Such parametric analyses are particularly valuable from the conceptual phase through the early development phase in selecting design approaches for further optimization.

8-3.2.2 Splice Band Trade-off

Table 8-5 presents a trade-off that was conducted to select the splice configuration for a missile reentry vehicle that comprises one section of a proposed surface-to-surface missile. The remainder of the missile consists of first and second stage propulsion sections. The major sections of the reentry vehicle are the terminal sensor section, the warhead section, and the guidance and control section. An adapter is provided as part of the reentry vehicle to facilitate mating to the second stage. The maintenance concept for the reentry vehicle at the site was replacement of one of its three major sections in case of malfunction. However, replacement of the total reentry vehicle was also a consideration.

The purpose of the trade-off was to determine the most cost-effective airframe design

TABLE 8-5. SPLICE BAND TRADE-OFF

PURPOSE

This trade-off was conducted to determine the most cost-effective airframe design for the reentry vehicle (RV). This study is based on operation and maintenance (O&M) costs for a 10-yr period.

GUIDELINES AND ASSUMPTIONS

1. The RV will be handled and maintained in accordance with the present military organization.
2. The quantities and types of countdowns accomplished by a tactical battalion are based on historical data.
3. Reliability data were based on preflight reliability allocations. The upper limit of the reliability range was used for worst case analysis, and the failures were normalized for the different types of countdowns experienced by the missile.
4. Hardware cost data were provided by Finance.
5. Design, maintenance and support costs that would be identical (or virtually identical) for all configurations were not documented. Only those costs that resulted in cost deltas (differences) among configurations were compiled:
   (a) Modification costs to the equipment used for test and checkout of the RV were not included, since no cost deltas result in relation to each of the RV candidates.
   (b) Repair part costs were not included, since the RV acquisition cost extremes among candidates are approximately $7.0K and are not a significant delta. Operational readiness float costs were included.
6. The preliminary maintenance concept for the RV was replacement of one of three major sections (terminal sensor, warhead, and guidance and control) at the site. However, other concepts will be investigated.
7. Manpower costs were obtained from the Army Cost Planning Manual.
8. The splice for the radome assembly is a shear splice, and RV separation from the adapter is an explosive charge.
9. The following four candidates will be studied.

Candidate 1: No quick splice
Candidate 2: One quick splice
Candidate 3: Two quick splices
Candidate 4: Two quick splices with inertial measurement unit (IMU) and computer section relocated from the guidance and control section into the terminal sensor section.

APPROACH

Each of the four candidates (see Fig. 11) was analyzed to determine the requirements for operational handling and disassembly for corrective maintenance. The cost parameters used included only those which were impacted by RV airframe design. As a result, the total costs depicted do not represent total life cycle costs, but costs which reflect differentials due to

TABLE 8-5. SPLICE BAND TRADE-OFF (Cont'd)

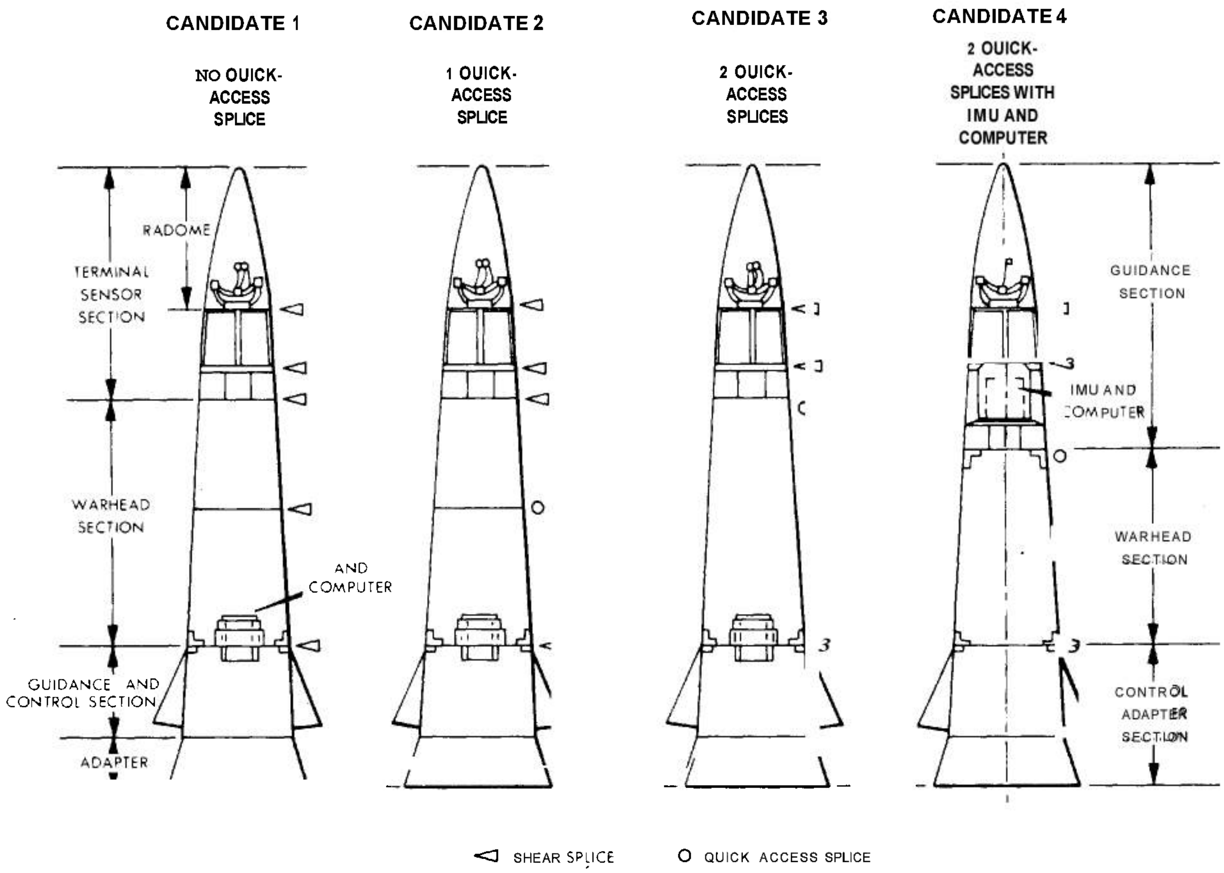


FIGURE II. RV FIELD SPLICE CONCEPTS

the RV airframe design. **The** study was conducted based on a three-battalion complement and included the following parameters:

Prediction of end item failures
Maintenance costs for assembly/disassembly of sections
Handling equipment identification and cost
Container cost
RV transportation cost from firing battery to maintenance facility
Special Ammunition Supply Point impact (personnel)
Modification cost
Support equipment at Special Ammunition Supply Point
Float cost
Publication and training cost
Impact on performance

TABLE 8-5. SPLICE BAND TRADE-OFF (Cont'd)

RESULTS

Chart III (RV Trade Study Cost Summary) delineates the basic costs and maintainability factors associated with the four RV candidates.

RECOMMENDATION

Based on the results of this analysis, it is recommended that Candidate 3 be selected, since it represents the lowest cost and complies with the system specification requirements for mean time to repair *(MTTR)*.

Comparison factors among RV candidates that support the selection of Candidate 3 and not the selection of the other candidates are delineated in the paragraphs that follow.

No Quick Splice (Candidate 1)

1. Requires the Armament Command (ARMCOM) to handle missile peculiar electronic hardware, which is a Missile Command responsibility.
2. Requires establishment of missile peculiar equipment test facilities and special RV handling dolly at each ARMCOM activity.
3. Requires that RV section repair floats be assigned and controlled by ARMCOM activities.
4. Requires complete RV operational floats, as well as peculiar repair cycle section floats, since section replacement is accomplished by ARMCOM and section repair is accomplished by the Ordnance units.
5. Dictates a maintenance concept of RV replacement at the firing site with no flexibility for other alternatives.

One Quick Splice (Candidate 2)

1. Requires a weapon configuration that can be handled without being in an RV warhead section structure.
2. Requires special weapon handling equipment mounted on a vehicle at the firing batteries to handle weapon and/or terminal sensor (TS) section replacement, since the weapon is mounted to the TS section.
3. Requires additional structure removal from both the TS section and guidance and control (G&C) section to place section(s) in the rear area maintenance facility for maintenance.
4. Warhead interface networks are under the cognizance of the Ordnance units and not ARMCOM activities.
5. Dictates a maintenance concept of G&C section replacement at the firing site with no flexibility for an alternative of repair by assembly replacement.

Two Quick Splices (Guidance Fore and Aft of Warhead Section) (Candidate 3)

1. Separates hardware support responsibility between ARMCOM activities and the Ordnance units.
2. Requires only common handling equipment, since hardware is packaged and separable in three distinct sections.
3. Section sizing is in compliance with space in rear area maintenance facility for maintenance.
4. Provides for the least impact on the existing maintenance and supply support organization.
5. Provides for a flexible maintenance concept that could include RV repair at the firing site by replacement of defective assemblies within sections.

TABLE 8-5. SPLICE BAND TRADE-OFF (Cont'd)

Two Quick Splices (All Guidance Forward) (Candidate 4)

1. Separates hardware support responsibility between ARMCOM activities and the Ordnance units.
2. Requires only common handling equipment, since hardware is packaged and separable in three distinct sections.
3. Section sizing is in compliance with space in rear area maintenance faciity for maintenance.
4. Provides for the least impact on the existing maintenance and supply support organization.
5. Guidance packaging results in combining relatively high and low reliable hardware, necessitating that the high reliable hardware go into a repair cycle for maintenance of the lower reliable hardware.
6. Requires removal of the guidance section battery and distributor to gain access to the IMU and missile computer.
7. Dictates a maintenance concept, without flexibility at the firing site, that section replacement is required for IMU and missile computer failures.

Chart III contains a summary of costs and quantitative factors that are calculated in the Appendix. The following paragraphs discuss guidelines for the calculations. Discussions are keyed to the major row headings in Chart 111, which are categorized as:

A – Acquisition costs
B – Maintenance costs
C – Support costs
D – Quantitative factors
E – Total costs

Category A – Acquisition Cost (each)

The costs in this row present the per item cost for the configuration of the RV identified. The difference in cost between the candidates 2, 3, and 4, compared to 1, is based on the following:

Candidate 1: Baseline
Candidate 2: Structure and networks for warhead on G&C and TS section
Adaption kit for weapon on G&C and TS section
Candidate 3: Structures, networks, and adaption kit on W/H section due to unsplice capability
Candidate 4: Separate control section (networks, structures, etc.)
Smaller W/H section
Separate guidance section integrated with TS section

Category B

(a) Maintenance Man-hour Costs

The maintenance man-hour costs are based upon the man-hours expended in unsplicing and splicing the various configurations, plus the additional impact of testing and replacing defective sections of RV by the Special Weapons Group for Candidate 1 configuration. In Candidates 2, 3, and 4, only the cost for unsplicing and splicing is considered; the additional testing by the Special Weapons Group is not required.

TABLE 8-5. SPLICE BAND TRADE-OFF (Cont'd)

(b) Handling Equipment

The costs depicted in this row are based on the handling equipment required for a three-battalion operation. Handling equipment includes the slings, hoist beams, dollies, weapon replacement equipment, etc.

(c) Containers

The costs depicted in this row are based on the containers required for a three-battalion configuration. The quantities include a basic load of 108, plus additional containers for float configurations. A complete RV container is used only in the Candidate 1 configuration.

(d) Transportation

The transportation costs include the man-hours and petroleum, oil, and lubricant (POL) costs for the candidates: Candidate 1 considers transporting RV sections from firing battery to the Special Ammunition Supply Point (SASP), and the subsections between the direct support unit (DSU) and the SASP for test.

(e) Personnel

Personnel costs are delineated for Candidate 1 configuration (no quick splice concept) for personnel at the SASP to perform RV maintenance. This maintenance includes test, assembly, and disassembly. Crew size is based on one programmer-test station operator/battalion and three missile crewmen. No additional personnel are required for Candidate 2, **3,** or **4.**

(f) Erector-Launcher (EL) Modification

The erector-launcher (used to transport the total missile and provide the launch pad) modification costs are the costs of the hardware, manpower, and modification work order preparation. In Candidate 1, the length of the RV is such that a rail system would be installed on the EL to support the RV for handling and assembly purposes. In addition, the pallet and davit would be removed from the EL. In the other configurations, the pallet would be modified with a new pallet cover and support assembly.

(g) Support Equipment

Support equipment costs include the costs of additional programmer-test stations, power stations, and power distribution sets at each of the battalions for test of the RV section at the SASP.

Category C – Support Costs

(a) Spare Operational Readiness Floats (ORF's)

Floats were allocated based on the failures predicted, turnaround time, and maintenance concept. Candidate 1 includes the floats for total RV section replacement located at the SASP, based on a 2-day turnaround and the individual section thereof for replacement of the SASP while sections are being repaired at a rear area maintenance facility. The cost of the weapon is not included in the total.

(b) Publications

Publication costs include the changes to 25 technical manuals in the areas of missile, erector-launcher, containers, handling equipment, and firing procedures. Rear area maintenance manuals were not considered, since there would be no cost deltas based on the configurations.

TABLE 8-5. SPLICE BAND TRADE-OFF (Cont'd)

(c) Personnel Training
The total cost of training related to the RV is $12,074K for a 10-year period. This includes training of key personnel, service training for three battalions and two general support unit platoons. Since there are no cost deltas for the various configurations, the training cost is not included for courses. Candidate 1 cost and hours are for the training of the personnel located at the SASP for a 10-year period for one programmer-test station operator and three missile crewmen per SASP.

(d) Training Equipment
The training equipment identified includes the trainer warhead, G&C proficiency trainer, terminal guidance proficiency trainer, warhead simulators, and containers for the trainers.

Category D – Quantitative Factors

These rows show the percentage of failures repaired using firing battery resources and the mean time to repair the failures, similar information for repairs using direct support resources, and an overall mean time to repair. The times include predicted supply and administrative time delays.

Category E – Total Costs

The costs in this row are the summations of the costs delineated in Categories B and C. The Category A unit RV costs were used to calculate float costs, but are not reflected otherwise in the total.

CHART III
RV TRADE STUDY COST SUMMARY*

	Trade Study Candidates			
	1 No Quick Splice	2 One Quick Splice	3 Two Quick Splices	4 Two Quick Splices
A. Acquisition Costs (ea), $K	385.6	392.7	390.3	385.6
B. Maintenance Costs, $K				
Man-hours	473.0	22.5	3.8	7.4
Handling Equipment	1,669.4	3,778.2	686.9	666.9
Containers	2,094.3	3,091.3	2,422.4	2,254.0
Transportation	3,043.2	2,893.2	2,893.2	3,772.5
Personnel	1,080.0	---	---	---
EL Mod	579.5	427.3	434.7	433.7
Support Equipment	2,443.2	---	---	---
C. Support Costs, $K				
Spare ORF's	6,477.2	4,712.4	4,683.0	8,202.0
Publications	2,487.3	2,399.1	2,354.8	2,354.8
Personnel Training	202.2	---	---	---
Training Equipment	1,748.0	1,829.2	1,805.6	1,753.2

TABLE 8-5. SPLICE BAND TRADE-OFF (Cont'd)

CHART III
RV TRADE STUDY COST SUMMARY (Cont'd)*

	Trade Studs Candidates			
	1 No Quick Splice	2 One Quick Splice	3 Two Quick Splices	4 Two Quick Splices
D. Quantitative Factors				
MTTR Org System				
%	64	91	91	91
Hrs	0.82	1.36	1.27	1.25
MTTR DS System				
%	36	9	9	9
Hrs	6.27	6.51	6.48	6.48
MTTR Hrs System	2.8	1.8	1.7	1.7
E. Total Costs, $ (excluding acquisition costs)	22,297,300	19,153,200	15,284,400	19,444,500

*Costs of design, maintenance, and support that do not result in cost differences among candidates are not included.

APPENDIX

Cost Calculations:

I Acquisition
II Failures per 10 yr
III Maintenance man-hour costs
IV Handling equipment
V Containers
VI Transportation
VII Personnel
VIII Erector-launcher (EL) modification
IX Support equipment
X Spare operational readiness floats (ORF's)
XI Publications
XII Personnel training
XIII Training equipment
XIV Quantitative factors

TABLE 8-5. SPLICE BAND TRADE-OFF (Cont'd)

I. Acquisition Costs

Acquisition Costs Per Item, $

Candidate	Adapter	G&C	W/H Section	TS Section	Radome	Total
1	24,122	214,815	11,015	126,514	9128	385,594
2	24,122	223,893	----	135,592	9128	392,735
3	24,122	214,815	15,759	126,514	9128	390,338
4	24,122	52,621 (Controls)	10,815	288,908 (Guid Sect.)	9128	385,594

II. Failures per 10 Yr (3 Battalions)

Failures Per 1000 Countdowns

Candidate		1st	2nd	Adapter/G&C	W/H Section	TS Section	RV
1	QC	3	4	18	1	8	27
	C	3	4	19	1	9	29
	S	3	4	19	1	9	29
2	QC	3	4	18	1	8	27
	C	3	4	19	1	9	29
	S	3	4	19	1	9	29
3	QC	3	4	18	1'	8	27
	C	3	4	19	1	9	29
	S	3	4	19	1	9	29
4	QC	3	4	5	1	21	26
	C	3	4	6	1	22	30
	S	3	4	6	1	22	29

Based on:

270 quick counts/month/battalion × 3 battalions = A
120 confidence/month/battalion × 3 battalions = B
610 standard/month/battalion × 3 battalions = C

The failure calculation for missile sections was based on the following:

(1) Total RV failures $= \dfrac{\sum_{i=1}^{n} (A\, a_i + B\, b_i + C\, c_i)120}{1000}$

TABLE 8-5. SPLICE BAND TRADE-OFF (Cont'd)

where

n = sections in the system

A = total number of quick counts

B = total number of confidence counts

C = total number of standard counts

a_i = number of failures based on quick count for section i from preceding table

b_i = number of failures based on confidence count for section i from preceding table

c_i = number of failures based on standard count for section i from preceding table

120 = factor for 10-yr conversion in months

1000 = factor for conversion to number of 1000 counts

Example

$$\text{RV failures} = \frac{[(270\text{x}3)(27) + (120\text{x}3)(29) + (610\text{x}3)(29)]120}{1000} = 10{,}246$$

111. Maintenance Man-hour Costs

The time for unsplicing and splicing the various configurations was derived from a splice trade-off and is 3180, 5977, 999, and 1997 man-hours, respectively, for Candidates 1, **2,** 3, and **4.** The cost for unsplicing and splicing the candidates is determined as follows:

Cost = Man-hours × hourly rates (in dollars)

The costs are $11.9K, $22.5K, $3.8K, and $7.4K, respectively, for Candidates 1, 2, 3, and **4.**

Candidate 1 also requires testing and defective section replacement at the special weapons test area. Four persons are required for the times indicated to accomplish the following activities:

Perform in-container test	0.5 hr
Remove container top	0.1 hr
Position RV dolly	**0.2** hr
Remove RV from container	**0.4** hr
Install RV on dolly	**0.3** hr
Place defective section in container	**0.3** hr
Secure container	0.2 hr
Remove replacement section and place on dolly from container	0.5 hr
Perform in-container test	0.5 hr
	3.0 hr

TABLE 8-5. SPLICE BAND TRADE-OFF (Cont'd)

Test and section replacement costs for Candidate 1 are:

Failures per 10 yr × man-hours per failure × hourly rate (in dollars) or,
10,246 × 12 × 3.75 = \$461.1K
Adding the \$11.9K unsplicing and splicing costs results in a total cost of \$473K for Candidate 1.

IV. Handling Equipment

The handling equipment and quantities for the four candidates are identified in the following table for three battalions:

Handling Equipment	Candidate			
	1	2	3	4
Complete RV hoist beam	39			
TS section hoist beam	9	46	46	
G&C section hoist beam	9	46	46	46
W/H section hoist beam	4	40	40	40
Control section hoist beam				46
RV container slings	39			
TS/G&C container sling	6	40	40	
Control/adapter container sling (G&C and W/H capability)	1	4	4	44
System components test station dollies (G&C and TS)	20	20	20	20
RV dolly	3			
M656	36			
Hoist	36			
Adapter kit	36			
Weapon replacement equipment		12		
3 Vehicles/battery		12		
Adapter kit		12		

The terminology of the handling equipment is basically the same; however, the configurations, and thus the costs, are different for the various candidates

Individual costs for items shown in the preceding table from top to bottom are:

\$6336, \$3033, \$3073, \$3659, \$446, \$444, \$444, (\$9437, \$11778), \$17604, \$20000, \$6650, and \$2488 for Candidate 1.

\$3802, \$3190, \$7230, \$421, \$421, (\$10051, \$11161), \$223208, \$20000, and \$1525 for Candidate 2.

\$3043, \$3083, \$4320, \$444, \$444, (\$9468, \$11816), for Candidate 3.

\$3018, \$3632, \$3058, \$442, and (\$10555, \$11721) for Candidate 4.

TABLE 8-5. SPLICE BAND TRADE-OFF (Cont'd)

V. Containers

The containers, quantities, and per item cost for the four candidates are identified as follows:

Container	Candidate 1		Candidate 2		Candidate 3		Candidate 4	
	Qty	cost, $	Qty	cost, $	Qty	cost, $	Qty	cost, $
RV container	120	16,725	120	13,379				
G&C container	6	8,920			120	8,920	132	10,035
W/H container	3	2,347			120	2,347	120	4,459
TS container	3	8,920	120	10,035	120	8,920		
Weapon containers			120	2,347				
Control/adapter container							120	3,286

VI. Transportation

The round trip travel time is as follows:

FB to SASP 9.0 hr
DSU to SASP 1.0 hr
SASP to SAS 10.0 hr

Transportation of the warhead requires three vehicles (two of which are for security) and six men; vehicles travel at an average speed of 35 mph with a fuel consumption of 10 mi/gal at 14 cents per gal.

Transportation of other sections requires one vehicle with two men.

Transportation and petroleum, oil, and lubricant (POL) costs for candidates are per battalion as delineated in the following table.

Item	Candidate 1 ($K) Trans	1 ($K) POL	2 ($K) Trans	2 ($K) POL	3 ($K) Trans	3 ($K) POL	4 ($K) Trans	4 ($K) POL
RV	842.4	18.4						
G&C section	19.5	1.3	487.5	28.6	487.5	28.6	780.0	51.0
TS section	7.8	0.5	198.8	11.4	198.8	11.4		
W/H section	117.0	7.5			222.8	15.3	205.5	13.3
Weapon			222.8	15.3				
Control/adapter section							195.0	12.7
Total ($K) (3 Battalions)	3,043.2		2,893.2		2,893.2		3,772.5	

TABLE 8-5. SPLICE BAND TRADE-OFF (Cont'd)

VII. Personnel

Personnel costs are based on one programmer-test station operator and three missile crewmen per battalion located at the SASP for RV maintenance on the missile system for each of three battalions.

It is assumed that personnel are rotated every 2 yr, are replaced with personnel that require basic training prior to assignment, and:

Annual pay and allowances are **$6,050** per individual.

Basic training, transportation, etc., cost **$5,900** per individual.

Then

$$\text{Personnel costs} = \text{System life in years (No. of personnel} \times \text{annual pay in dollars)} + \left(\frac{\text{System life in years}}{2}\right) \times \text{(No. of personnel} \times \text{training cost in dollars)}$$

$$= 10 \times 12 \times 6{,}050 + (10/2) \times 12 \times 5{,}900 = \$1{,}080\text{K}$$

These costs apply only to Candidate **1**

VIII. Erector-Launcher (EL) Modification

The EL modification costs are shown in the following table for the four candidates. Costs are based on a **$16.50** man-hour rate for the modification team effort, and **115** EL's.

Item	Candidate			
	1	**2**	**3**	**4**
Modification	Install **4** rails Remove davit Remove pallet	Add support to pallet Add new pallet cover	Add support to pallet Add new pallet cover	Add support to pallet Add new pallet cover
Costs, $K:				
Man-hours	**41.8**	8.5	8.5	8.5
Kit	**536.4**	**418.5**	**425.9**	**424.9**
MWO	**1.3**	**0.3**	**0.3**	**0.3**
Total, **$K**	**579.5**	**427.3**	**434.7**	**433.7**

TABLE 8-5. SPLICE BAND TRADE-OFF (Cont'd)

IX. The support equipment costs are shown for the additional programmer-test station (PTS) located at the SASP areas at the three battalions for the test and maintenance of the RV section. This includes both PTS, power station (PS), and power distribution set (PDS) to complete the test of the assembled RV section successfully.

Total cost:

3 PTS at $600K = $1,800.0K
3 PS at $200K = $ 600.0K
3 PDS at $14.4K = $ 43.2K
$2,443.2K

There is no additional cost for Candidates **2, 3,** and **4.**

X. Spare Operational Readiness Floats (ORF's)

Spare ORF's and repair cycle floats (RCF's) were selected based on the failures predicted on the replaceable sections, the turnaround time, and the maintenance concept for the system. The following table delineates the quantity and per item cost of floats.

	Candidate							
	1		2		3		4	
Item	Qty	cost, $K	Qty	cost, $K	Qty	cost, $K	Qty	cost, $K
RV	12	385.5						
G&C section	6	238.9	12	248.0	12	238.9	24	298.0
TS section	3	135.6	12	144.7	12	135.6		
W/H section	1	11.0			12	15.75	12	10.8
Control/adapter section							12	76.7
Total, $K	6,477.2		4,712.4		4,683.0		8,202	

Sections, as defined, differ for each candidate in accordance with the configuration.

XI. Publications

The cost of publications includes initial impact and changes to the missile, erector-launcher, container, handling, and firing position procedure manuals as a result of the four candidates. The cost summary is shown in the following table.

TABLE 8-5. SPLICE BAND TRADE-OFF (Cont'd)

Item	1 ($K)	2 ($K)	3 ($K)	4 ($K)
	Candidate			
Initial	836.9	811.4	795.6	Same as 3
Changes	1,650.4	1,587.7	1,559.2	Same as 3
Total, $K	2,487.3	2,399.1	2,354.8	2,354.8

XII. Personnel Training

This cost category is comprised of the costs associated with training unique to the candidates. There are no cost deltas except that Candidate 1 requires added training for one programmer-test station operator and three missile crewmen at each of three special weapon test areas.

During the system life, six training cycles will be required for Candidate 1. For each cycle, the average training cost per individual is $2808.

Average individual training cost × No. of individuals × No. of training cycles = training cost delta

$2808 × 12 × 6 = $202,176.

XIII. Training Equipment

Training equipment costs and quantities are summarized in the tabulation that follows. Costs are shown on a per item basis.

	Candidate							
	1		2		3		4	
Item	Qty	cost, $K	Qty	cost, $K	Qty	cost, $K	Qty	cost, $K
Trainer warhead	12	12.6			12	17.4	12	12.4
Container	12	2.3			12	2.3	12	4.4
G&C proficiency trainer	4	238.9	4	248.0	4	238.9	4	298.0
Container	4	8.9	4	13.3	4	8.9	4	10.0
TS proficiency trainer	4	135.6	4	144.6	4	135.6		
Container	4	8.9	4	10.0	4	8.9		
W/H simulator			36	4.6				
Control/adapter trainer							4	76.7
Container							4	3.2
Total, $K	1,748		1,829.2		1,805.6		1,753.2	

TABLE 8-5. SPLICE BAND TRADE-OFF (Cont'd)

XIV. Quantitative Factors

The values shown in these rows are the percentage of failures repaired, using firing battery resources, percentage using direct support resources, the mean time to repair for each, and the overall mean time to repair. Values presented are based on initial predictions.

and the optimum maintenance concept, with operation and maintenance cost and the mean time to repair as major decision parameters. The trade-off, although primarily one of a quantitative nature (i.e., costs and repair time), also considered qualitative features such as flexibility in the maintenance concept and separation of maintenance responsibility among commands.

The trade-off was addressed to the category of splice to be used in configuration of the airframe. The splice type categories were the shear splice and quick-access splice. The shear splice is a factory type of splice that consists of multiple screw fasteners around the periphery of the section to mate the sections together. The quick-access splice is a field maintenance type of splice (i.e., vee band, spline splice, etc.) that provides for rapid mating and unmating of sections.

In addition to determining the airframe design, the trade-off also provided the decision data from which the optimum maintenance concept was selected and—within this concept—considered the costs of handling equipment, transportation, personnel, modification, operational readiness and repair cycle float requirements, publications, and training.

8-4 OTHER REQUIRED SYSTEM DATA ELEMENTS

A data element is defined as a basic unit of information having a unique meaning and consisting of subcategories of distinct units or values. A data item is a subunit of descriptive information, or a value classified under a data element. Hence, data elements are comprised of data items (Ref. 8). These data items are not to be confused with data item descriptions such as those contained in contractor data requirement lists.

Data systems are designed to receive and manipulate data elements, and to provide management summaries, narrative information, data element statistical data, etc., as outputs. It follows that prior to the development of a data system, it is important first to decide what is required as outputs, and second to decide what data elements are required to provide the outputs. The data system then can be designed. Since the system is designed for a unique set of data elements, all input data must be in terms of the elements.

This process is followed in the formulation of all Army data systems, and the reporting of the data to these systems is in standardized terms, other than when a data element permits a narrative entry. Table 8-6 is a partial listing of data elements for a maintenance management system.

8-4.1 DATA SYSTEM CHARACTERISTICS

The use of data system information to conduct trade-offs is discussed in par. 8-3.2. This is only one application of data system information. The underlying objective of a data system is to provide management information applicable to desired phases of management, and data elements must be selected accordingly. A maintenance engineering analysis data system is designed specifically to manage the development and acquisition of a materiel support subsystem. Maintenance and depot management systems, as a group, are designed specifically to manage the operation and support of deployed materiel. In each case, management of support should be construed as including the function of influencing design to attain optimum supportability.

TABLE 8-6. TYPICAL MAINTENANCE MANAGEMENT SYSTEM DATA ELEMENTS (Ref. 3)

Failure Code	Miscellaneous Code
Detected Failure Code	Equipment Calibration Code
First Indication of Trouble Code	Not Repairable This Station Code
Action Code	Motor Vehicle Use and Supply Status Code
Part Source Code	Reason for Transfer Code
Utilization Code	Equipment Loss Code
Time Conversion Code	Equipment Gain Code
Calendar Date to Julian Date	Other Reporting Code
Scheduled Service Code	Equipment Category Code

A data system should provide for receipt of all required data elements, and for uniform treatment of these elements. Receipt of the elements in the proper format may be realized best by providing reporting personnel with standard reporting forms. Such forms should be as simple as possible, thereby minimizing the probability that the data will be entered improperly on the form. Additionally, reporting personnel should be instructed in both the use of the forms and the importance of filling them out correctly. The completed forms should be subjected to some form of quality audit by supervisory personnel before submission.

The utility of the output of a data system is governed largely by the adequacy of the input data. These data should be in sufficient depth to serve the intended purpose and should be accurate. The designer of a data system is responsible for the depth of the input data and can enhance system accuracy by minimizing the number and complexity of required input data elements. Reporting requirements should be compatible with the reporting time available to the reporter and with his technical and writing capabilities. Continuous and stringent supervision of the reporting activity also will enhance data reporting accuracy.

Once the data elements are received at the data processing center, subsequent actions pertaining to data storage, analysis, retrieval, and dissemination may be either manual or automated. When data quantities are limited and data inputs are not subject to frequent change, a manual system is desirable. The data can be received, analyzed, and reduced to some useful summary format, such as a graph or chart, and filed. In such a case, the system can be updated with new data simply by retrieving and updating the summary format. This virtually eliminates the retrieval problem. Even if detailed data retrieval is frequently necessary, the application of modern filing methods will alleviate the problem. The use of a manual system does not preclude the use of a computer to analyze data, and normally does not pose a data dissemination problem. The most significant advantages of a manual system are economy and immediate access to the data.

8-4.2 AUTOMATED DATA SYSTEMS

In an automated system, data element reporting forms usually require coded information. The use of codes permits the system to select and sort information in the manner and form required by the analyst. Codes, however, have limitations, and to describe precisely an action or event, the number of codes would become infinite. Therefore, the basic coded data should be supplemented by narrative type of data. This type of data will enable the data collector to inform the analyst of the precise conditions under which most situations are observed. The narrative remarks which are associated with and which expand recorded data are infinitely variable. They must be recorded in sufficient detail to be communicated effectively to the analyst who must make judgments and reach engineering decisions on the basis of the information provided.

Fig. 8-3 shows functional flows of the collection, analysis, and utilization of data, in a

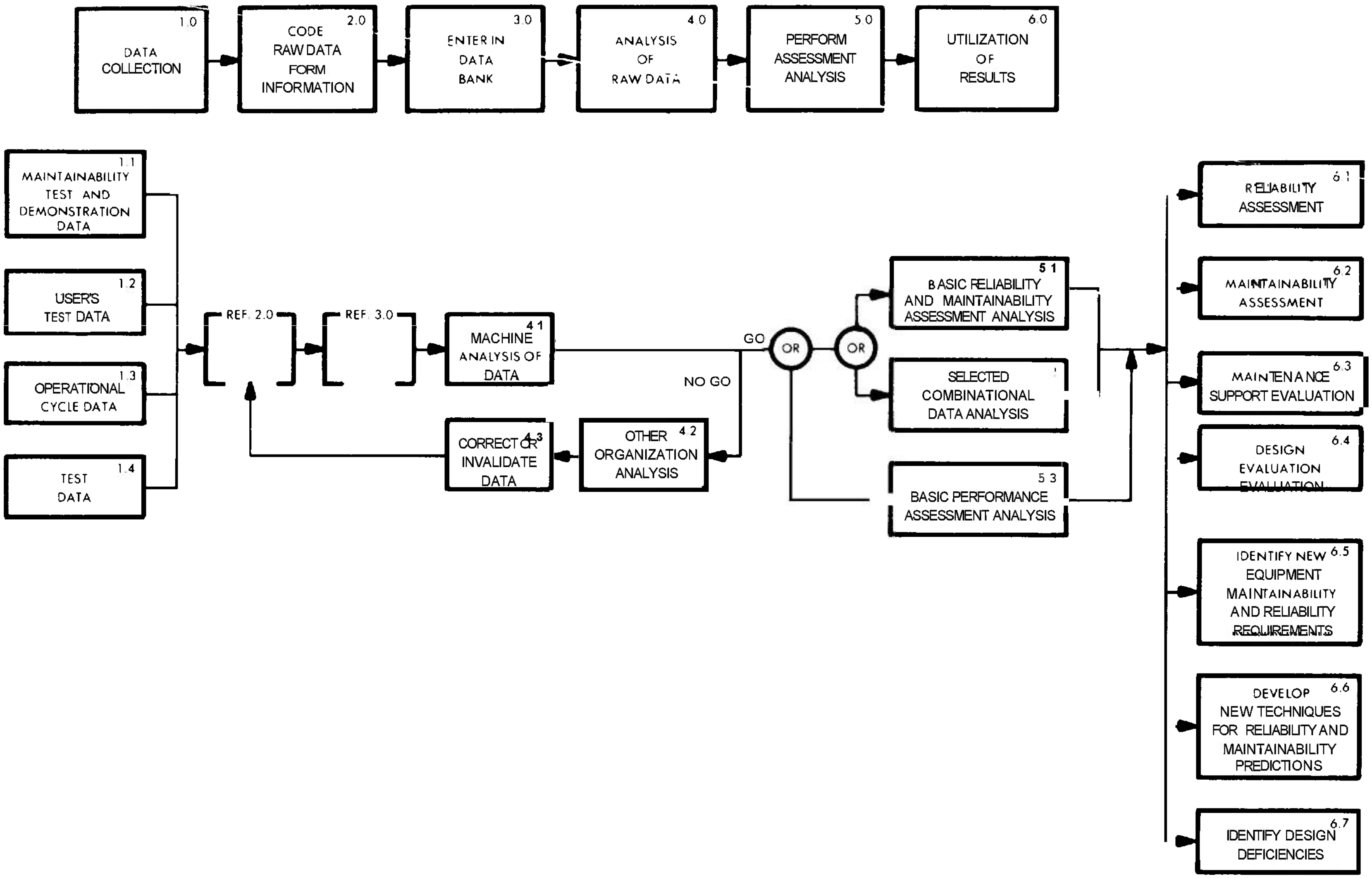


Figure 8-3. Data Flow in Automated System

typical automated data system. The upper flow diagram shows the major steps; the lower diagram shows the secondary steps within each major step, with the same major step block number. In the system, data are collected from the sources shown and are transmitted to the data processing center. Here, the data are coded and entered into the computer data bank, where the computer analyzes the data for content and format. Data not passed by the computer are analyzed manually and either are corrected and placed back into the bank or are discarded. Data passed by the computer are subjected to one of three analytical processes, and the results are utilized as shown.

Materiel and its support subsystem are developed with the assistance of a maintenance engineering analysis data system that contains data unique to particular hardware. After deployment, the management of materiel operation and support is effected with a maintenance management system that must accommodate dissimilar hardware. The complexity of such a data system and its operation are easily visualized. The Army Materiel Command is responsible for maintaining and operating the data system, and has assigned the responsibility to one of its organizations. This agency is the central point within the Army for the collection, summarization, and distribution of data generated by The Army Maintenance Management System. In that capacity, it is the servicing activity in the provisioning of data and special summary reports to installations, activities, commodity commands, and project/product managers in support of their equipment control applications and related industry support (Ref. 9).

The commodity command is the Army element primarily responsible for the management of logistic support of specified systems and items, components, or repair parts. Utilization of selected management by exception reports generated from The Army Maintenance Management System data assists commodity commands in effective accomplishment of functional responsibilities in the following areas (Ref. 9):

a. Evaluation of equipment and component failures

b. Improvement of equipment reliability

c. Improvement of equipment maintainability

d. Control of equipment modifications

e. Increasing equipment readiness posture

f. Equipment standardization

g. Establishment of reliable maintenance planning factors

h. Computation of repair part requirements

i. Development and revision of overall criteria and programs.

The data provided by the data management agency are concerned with the following categories of maintenance information (Ref. 9):

a. Materiel usage status is applicable to equipment by location and organizational assignment, age, condition, usage, and usage rates.

b. Materiel readiness is applicable to authorized quantities, on-hand quantities, availability, operational readiness, not operationally ready supply, not operationally ready maintenance rates.

c. Maintenance accomplishments and planning factors include maintenance functions, man-hours, part usage/cost, periodic services, mean time between failures, mean time to repair, number of maintenance actions, average man-hours per item of equipment by function, and quantity and type of parts used.

d. Modification work order status is applicable to formal modification programs.

The data elements reported through The Army Maintenance Management System vary by equipment commodity. Maintenance operational data not provided by this system may be obtained by a special operational data collection procedure.

8-5 COST ANALYSIS

Maintenance engineering activities can have a major influence on the total cost of ownership of Army materiel. For example, maintenance support guidance provided during the formulation of a required operational capability and the subsequent maintenance engineering analysis process both impact total ownership costs; they can assist either in driving the costs up or forcing them down, depending on the effectiveness of these activities.

Consider first some of the general areas where system costs are impacted by maintenance engineering analysis. Since these analyses are iterative, their effects will be felt throughout the materiel life cycle. During the program conceptual and validation phases, analyses develop qualitative and quantitative logistic support objectives. As the program progresses, these objectives are refined into design parameters for use in various trade-offs, risk analyses, and development of logistic support capabilities. The initial effort evaluates the effects of alternative hardware designs on support costs and operational readiness. During design, analysis is oriented toward assisting the designer in incorporating logistic requirements into hardware design. The goal is to create optimum materiel that meets the specification and is cost-effective over its planned life cycle.

Maintenance engineering analyses provide cost relatable inputs to logistic simulations, cost-effectiveness models, design trade studies, and life cycle cost analyses. As design development progresses, quantitative analytical techniques and cost-effectiveness studies are used to make repair or discard, level of repair, life cycle maintenance costs, and related determinations, and to identify further economic or operational advantages that can be realized in the design of the maintenance support structure for the system or equipment.

Cost analyses associated with maintenance engineering analyses during the conceptual and validation phases are especially critical and require intensive management. The primary source of data at this point in the program life cycle is historical data. These data encompass supply, maintenance and operational information from existing systems, and other Service or contractor information such as technical reports, combat records, and field exercises, as appropriate. It is during this time that historical data are used to quantify design characteristics versus support costs. Also during this time, support systems are synthesized, and each candidate must have a cost associated with it in order that the comparative cost-effectiveness of each support system can be gauged. Finally, as a result of the support system synthesis, the candidate system that provides economical, effective support of mission requirements can be evolved.

Another major area where maintenance engineering has an early interface with and impact on life cycle ownership cost is during initial maintenance support planning. The guidance provided to the materiel developer and procurement agencies for use in developing technical requirements for new materiel influences decisions that involve support costs. Typical of the information provided to these agencies by the maintenance engineering function are maintenance support concepts, parameters and criteria, quantitative equipment performance and maintenance performance data, and support cost data for similar equipment in the inventory. The cost associated with each input category can have far-reaching effects on the estimates for cost of ownership of new materiel. Later in the life cycle, but prior to the validation decision, finite goals for life cycle ownership cost must be established and documented in the program development plan. Here again, maintenance engineering contributes heavily because these cost goals reflect, to a great extent, the degree of cost-effectiveness built into the maintenance support plans generated as a part of maintenance engineering activities.

8-5.1 MAINTENANCE COST FACTORS

The intent of conducting cost of ownership analyses is to provide one of the inputs required to make a proper decision concerning the use of resources, but it is not the decision-making process itself. The output from these analyses can greatly influence these decisions, since a program life cycle cost quite frequently exceeds 10 times the cost of the combined development and procurement costs.

The cost factors that are used during these analyses are based upon pertinent data provided by the procuring activity from surveillance of operational systems. These factors may be measured in terms of manpower, equipment, facility space, and supplies normalized to dollars to provide visibility to the decision maker in each of these cost sensitive areas. These historical data establish a basis for logistic support requirements for new acquisitions and provide indications for special attention if significant deviations from established support concepts are noted. Data may furnish insight to justify new approaches or significant departures from traditional concepts. Such changes may consist of reducing or increasing the allocation of resources for maintenance, establishing different support procedures, reallocating maintenance workloads among the different levels of maintenance, or changing the concept for built-in versus manual checkout equipment. The identities, sources, and application of historical data should be defined clearly to facilitate verification.

Typical cost factors that impact cost of ownership are (1) labor used in maintenance, (2) equipment inventories, (3) unserviceable items awaiting maintenance, (4) personnel training, (5) repair parts, (6) facilities, (7) special tools, (8) contract maintenance versus military maintenance, and (9) equipment publications. Each of these factors will be discussed in order to provide greater insight into their constituent parts.

8-5.1.1 Labor Used in Maintenance

This category encompasses all civilian and military manpower expended at all levels of maintenance for the equipment being analyzed. Maintenance is costed on an hourly basis for the number of hours actually expended accomplishing maintenance. With respect to levels of maintenance, organizational maintenance covers the maintenance performed by battery or battalion maintenance personnel. It does not cover operator maintenance, since operators are costed under personnel on a full-time basis. Field maintenance covers the direct and general support maintenance levels. Depot maintenance is costed separately.

8-5.1.2 Equipment Inventories

The quantities of equipment procured determine, to a great extent, the resource requirements that contribute most heavily to life cycle cost of ownership. This factor—sometimes called density—determines requirements for repair part stockage, transportation, maintenance facilities, support and test equipment, etc. This factor is used in virtually all life cycle cost of ownership analytical models because of its significant cost contribution.

8-5.1.3 Unserviceable Items Awaiting Maintenance

This factor also is known as the mean time awaiting repair and in most cost effectiveness models is the mean time a failed component end item spends in a queue awaiting repair. It can have significant cost impact since it increases the quantities of equipment in the maintenance float program. This time awaiting maintenance can be cost-quantified and used in cost of ownership analyses.

8-5.1.4 Personnel Training

Personnel training is divided into several cost categories. Initial training is given military personnel to qualify them in the skill and to the level required by their assignment in the operating and maintenance units required by the system. New equipment training is for a cadre of personnel who will subsequently teach personnel at service schools and is also a training cost. Recurring training is the training of replacement personnel, the requirement for which is created by attrition rates, rotation policies, promotions, etc. Retraining of personnel required because of changes in system design also comes under this heading. In this case, the change bears this cost, and the life cycle cost pertinent to the change will be considered in the change approval decision loop.

When the quantity of personnel that must be trained annually is considered, it becomes apparent that this is a major factor in the cost of ownership.

8-5.1.5 Repair Parts

Funding for repair parts can represent a sizable portion of available program dollars. A major expenditure normally is made for initial repair part stockage. The repair parts procured during initial provisioning normally are limited to those required for all categories of maintenance during the initial support period. "Initial support period" means that amount of time required to replenish stocks through normal supply channels. In this connection, the following procurement and delivery policies are observed in determining fund requirements:

a. Repair parts procured concurrently with the end item normally are peculiar parts first being introduced into the supply system. Procurement of standard parts that already are in the supply system normally can be deferred due to reduced procurement lead time requirements. Procurement in both cases must satisfy initial allowance, pipeline, and replacement requirements for an initial support period.

b. Repair parts should be phased for delivery in increments proportional to end item delivery.

c. Deferred procurement (delaying repair part orders for subsequent fiscal year procurement) should be used whenever possible for end items whose delivery and deployment are spread over a period of more than a year.

Initially, repair parts are not provided always according to the foregoing procurement and delivery policies. There are at least two other basic concepts. The first of these is the buffer depot concept, whereby the prime manufacturer establishes what is, in effect, a bonded depot to provide repair parts for items that are subject to design change. He supplies parts in response to user requisitions until some time prior to the end of the production contract when the parts are placed into the military supply system. The second concept involves the use of contractor logistic support, whereby the contractor is funded to provide maintenance and/or supply services for some period of time after initial deployment. At the expiration of this time, the parts are placed into the supply system.

Each method of providing supply support normally will result in unique costs. Life cycle totals probably will be different and program years in which costs are incurred definitely will be different. Regardless, of the supply method(s) selected, the cost of repair parts required for initial stockage, pipelines, floats, and washout replacement represents a key ownership cost factor.

8-5.1.6 Facilities

New construction of buildings and installation of real property installed equipment are the principal constituent parts of the facility cost factor. The cost of facility maintenance is also a part of the cost factor, but few factorial values for Army-wide use are available. For that reason, each analysis must be handled on a case-by-case basis with whatever factorial Values are considered appropriate at that time. This cost factor can be of financial significance for some commodity lines. Consider, for example, a new fixed-site missile weapon system entering the inventory. This missile could require assembly on site. In this case, a rather elaborate missile assembly building would be required. If the sites are geographically diverse, X number of these buildings would be required. The cost of the buildings and their annual maintenance would be legitimate cost of ownership factors.

8-5.1.7 Special Tools

Creation of requirements for special tools and test equipment generally incurs a cost burden against the cost of ownership for a system. Requirements for these items can result from an inadequate maintenance engineering analysis. The Army has listings of both the tools and test equipment that are available for maintenance engineering study. Typical of these are lists of existing and proposed test, measurement, and diagnostic equipment, by commodity command (Ref. 10). Determination of special tool and test equipment requirements should be made only after exhaustive research of Army and Department of Defense resources has been conducted and cost trade-offs have been accomplished. In some cases, there is a tendency to specify nonstandard equipment that is far too sophisticated for the Army user simply because it worked well under laboratory conditions during the development phase when highly qualified technicians were available to use the equipment. It should be remembered that in most cases when special tools and test equipment become a legitimate program requirement, costs start to accumulate rapidly. Documentation is required, stock numbers must be assigned, cataloging is required, and costs to enter and maintain the items in the inventory are incurred; in short, there is a cascading effect that impacts cost of ownership of a particular system.

8-5.1.8 Contract Maintenance vs Military Maintenance

The decision to use contract maintenance for non-Table of Organization and Equipment (nontactical) materiel also can impact cost of ownership. It is Department of Defense and Army policy that reliance will be placed on contract maintenance for the provision of materiel maintenance services to the maximum extent consistent with effective and efficient accomplishment of Army programs and missions.

Support or depot level maintenance services which need not be performed in-house because of military readiness requirements and which can be obtained from private business concerns at an estimated annual cost less than the value specified by current regulations should be obtained by contract. However, when it appears that inadequate competition or other factors are causing commercial prices to be unreasonable, a comparison cost analysis of alternative methods of obtaining the required service should be made to determine the least costly option.

When the decision to rely either upon Government in-house activities (Army-operated or interservice/agency support) or contract maintenance to provide the needed maintenance service is to be made based on relative cost, a comparative cost analysis must be undertaken to provide the basis for the decision. When considerable quantities of nontactical equipment are associated with a weapon system mission, this can become a key cost factor.

8-5.1.9 Equipment Publications

This cost factor involves the funding required to obtain initially and update constantly the equipment publications used for maintenance and training associated with tactical equipment. The preparation task consists of research, writing, editing, typing, proofreading, printing, validation, and verification. Depending upon requirements, preliminary manuals may be issued to the user with minimum change, or republished and issued.

Once the publications are issued, they must be maintained current. Changes to these documents occur throughout the equipment life cycle. Some of the most significant causes of these changes are cataloging changes, design changes, maintenance and logistic support policy changes, and operating and maintenance experience. Cataloging changes can result from activities such as design changes, federal stock class code changes, and item manager changes, and result in changed stock numbers. Design changes also may impact maintenance, operating, and training procedures. Maintenance policy changes such as extending oil change intervals to conserve petroleum products affect maintenance procedures. Finally, requirements to change operating, maintenance, and/or training procedures may result from operating and maintenance experience.

Considering that a library of publications for a major weapon system consists of documentation covering the system, organizational maintenance, field maintenance, depot maintenance, supply, and training, it is apparent that this category represents a significant factor in the cost of ownership.

8-5.2 LIFE CYCLE COST ANALYSIS

Defense expenditures for 1960-1973 coupled with a projection of expenditures through 1980 are shown in Fig. 8-4. The projection assumes no reductions, and increases are based on retaining the 1973 purchasing power in subsequent years. Analysis of Fig. 8-4 provides some insight into the Department of Defense budget dilemma. In 1965, the budget was $47.1 billion, and in 1980, is projected to be $110.9 billion. This represents an increase of **135** percent. During this same time frame, military personnel costs and operation and maintenance costs are anticipated to increase 155 percent. More significantly, the dollars available for Research, Development, Test, and Evaluation (RDT&E) and hardware procurement increases only 98 percent. These curves indicate that the hardware dollars are being eroded by disproportionate increases in the costs to man and maintain weapons.

The rising cost of weapon systems, coupled with loss of buying power, has produced a dilemma; the Department of Defense either must acquire fewer systems, be satisfied with a smaller force, or find ways to effect drastic reductions in the cost of acquiring and supporting new systems.

The weapon system cost problem is complicated further by an inherent lack of visibility. Weapon system costs usually are identified with the development investment and associated procurement dollars. Yet the bulk of the costs is associated with operations and maintenance, manpower, training, and indirect support. Generally, the Department of Defense does not have

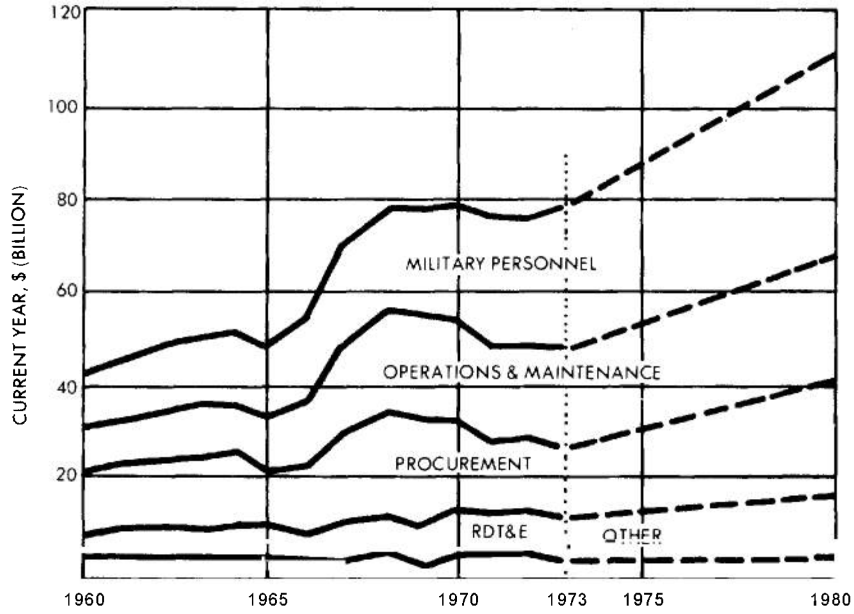


Figure 8-4. Defense Expenditures 1960– 1980

an accounting system that permits realistic and timely assessment of total ownership costs.

Faced with the prospect of declining budgets and rising costs, the maintenance engineering tasks assume more importance. One of the areas where great contributions can be made is in structuring credible cost estimates to support program management decisions. Analytical tools have been developed to assist the maintenance engineer in accomplishing this task. These generally are categorized as the cost estimating relationship and the engineered cost estimate methods.

8-5.2.1 Cost Estimating Relationship (Ref. 11)

If there are prior hardware systems which can be compared with the new (proposed) system, and if physical, performance, and cost data are available on the older systems, then statistical analysis may provide useful cost projections. Through curve-fitting techniques, system cost may be related to a combination of measures of the system (its dimensions, performance, etc.). Similarly, the costs of some types of subsystems may be related to their physical and performance attributes. The relationships commonly are called "cost estimating relationships". The method sometimes is called "parametric costing", because the physical and performance measures commonly are called parameters in the estimating equations.

Situations occur in which cost estimates are desired or required, but the information necessary for explicit estimating relationships is unavailable. At such times, highly subjective ("ball park") estimates frequently are made and can be justified as more useful than no estimate at all. Such estimates reasonably can be thought of as "implicit cost estimating relationships", inasmuch as the estimator subconsciously (or at least not overtly) is extrapolating from prior' experience through use of an unformulated or vaguely conceived relationship of the new item to older items.

Cost estimating relationships can reflect total system development, production, and/or operating and support costs. They can reflect individual segments of those costs or a composite of all costs. The segments usually are large, and the number of independent variables (or parameters) usually is small. Most of the estimating relationships used in past acquisitions have omitted operating and support costs, or have included them only partially.

It should be remembered that use of the cost estimating relationship method depends upon judgment that the historical data processed into the relationship reflect sufficient commonality with the proposed new item being costed to give a reasonable cost estimate of the latter. When the effects of inadequate commonality can be estimated, an adjustment may be made to the estimating relationship. Advantages and disadvantages of the cost estimating method are presented:

a. Advantages. The estimating relationship method has several advantages:

(1) It may be used early because it can be and usually is based on broad performance parameters and configuration concepts, rather than on detailed design. Generally, its use should start during the conceptual phase.

(2) It can be used rapidly and inexpensively. Hence it can be used for numerous possible versions of the system.

(3) It is less susceptible to the motivational bias of its users than other costing methods. It is not wholly free of bias, because its general shape and the choice and values of some of its parameters may be determined subjectively. Its objectivity advantage is sufficient, however, to justify its continued use along with more detailed methods once such methods are possible.

(4) It can provide confidence intervals as well as expected values of cost. Of the variety of curve-fitting schemes that have been used for the derivation of estimating relationships, regression analysis is the most common and has enabled ready computation of confidence intervals.

b. Disadvantages. Along with the advantages come disadvantages, namely:

(1) It is not applicable to radically new systems. The statistical relationships used are derived from experience, and that experience must be relevant to the new system. Hence, the new system must fit into an existing family of systems or be similar enough to such a family to justify use of the cost estimating relationship method, perhaps with some adjustment. Consequently, this method cannot produce reliable results for a system that depends heavily on new technology or incorporates drastically different design features.

(2) It may require adjustments even when the method is used on systems that are not radically different from their predecessors. There are economic trends, cost ratios, design practices, manufacturing methods, and operating and support precepts which are not explicit parts of the estimating relationship and which are changing continually. They cause the relationships to become gradually less accurate and to need revision.

(3) When separate estimates are required for system elements—such as built-in test equipment, gun laying equipment, data, system engineering, tooling, mock-ups, repair parts, replacement training, fuel, or pay and allowance of enlisted personnel—the method either fails or becomes like highly detailed methods of estimation, which rely on unique cost details for each system element. It also becomes more expensive to use, as finer details are to be separately costed, because of the need for development of additional estimating relationships. Therefore, the cost estimating relationship method most generally is applied in making development and design trade-offs at very high levels of aggregation. On the other hand, in the creation of detailed approaches to estimation under conditions where direct engineering or production cause-and-effect relationships are not known, or where cost inputs are not definitively known, cost estimating relationships may be the best method for constructing some of the detailed submodels of the overall system cost model.

(4) Most published works on estimating relationship models generally do not include operating and support costs, except occasionally for operating manpower and fuel. The few which attempt broader coverage of operating and support costs tend to have two weaknesses: (a) they reduce the feasibility of actually using them by incorporating parameters that are difficult or impossible to cost; and (b) they involve so much detail that many specifics of design are required, thus making it necessary to defer their actual application until later phases of the acquisition process.

The lack of development of cost estimating relationships for use in forecasting operating and support costs has forced reliance on the use of implicit cost estimating relationships for those costs until substantial design information is available.

8-5.2.2 Engineered Cost Estimate (Ref. 11)

As information about the hardware system and its use increases, and as the Department of Defense approaches decisions committing progressively larger amounts of money, more detailed life cycle costing becomes warranted and also becomes progressively more feasible. The engineered cost estimate method can then be applied. Total system cost is determined by summing the costs of many detailed cost elements. The elements are related through cost equations that reflect in detail the way the elements interact when the system is developed, produced, operated, and supported. The equations are expected to reflect the real world so closely that they can be said to be "engineered". They differ from the equations used in the regression analysis which create cost estimating relationships. The engineered equations follow more closely the step-by-step, cause-and-effect relationships in a microscopic examination of the sequence of events in the real world. Regression analysis equations addressed to an identical cost aggregation deal with statistical patterns in more of a macroscopic approach and with less inherent capability to reflect departures from past conditions.

As an example of the preceding distinction, consider some past cost estimating relationship estimates which have taken the position that operating and support costs equal a certain percentage (e.g., **225** percent) of production cost. Engineered estimates of the percentage relationships of operating and support costs to the same production costs will vary widely from case to case.

The engineered cost equations are filled in with estimates of the values of the many elements. The estimates of the elements, their subtotals, and their totals are examined and revised, where the revisions reflect either improved knowledge of the anticipated costs or revised decisions based on continuing trade-off analysis to make the system as cost-effective as possible. Such a process yields engineered cost estimates.

Generally, use of the engineered cost estimate method becomes possible at about the same time it becomes needed from the standpoint of decision making. Step-by-step, decisions on hardware and on operational and support concepts must be made, the timing of each being governed by leadtime considerations and prerequisite decisions in the overall acquisition process. As each decision is made, the latest (and presumably best) estimates are used concerning alternative implications for life cycle costs and system effectiveness. Thus, there is a gradual transitioning from cost estimating relationships to engineered cost estimates rather than a single changeover point for the entire system. When there is enough knowledge of the system to warrant initiation of full-scale development, there should be enough knowledge to initiate detailed cost analyses. Prior to that time, the same unknowns that preclude a decision to proceed with development also preclude reliable estimation of costs. Advantages and disadvantages of the engineered cost estimation are presented:

a. Advantages. There are numerous reasons for using the engineered cost estimate method as soon as conditions for its use have been met, namely:

(1) It can be more accurate than cost estimating relationships because it usually incorporates expert inputs at detailed levels. Different elements can be estimated by different people, and each element can be small enough to be within an individual's area of expertise and awareness of the latest information (test results, cost of proposed improvements, etc.).

(2) It can be applied independently to the various parts of the system. Hence, for system segments on which firmer descriptive information is available at an earlier stage, this cost method can be used to adjust or replace the results of the estimating relationship method.

(3) It can contain enough detail to permit study of cost differences among competing functional proposals (for production, development, inspections, support procedures, etc.). Rules for use of the method should be clear and definite, so that proposals prepared accordingly can be compared. Sufficient specifics can be included so that comparisons will illuminate specific functional areas and amounts of cost difference.

(4) It allows more detailed simulation and sensitivity studies to be made, because it permits individual elements to be scrutinized and it allows costs to be regrouped in numerous ways.

b. Disadvantages. As with other methods, there are also drawbacks, namely:

(1) It cannot serve effectively as the primary costing method until detailed information is at hand. By that time, certain prior decisions already will have removed some of the latitude in considering alternatives which now appear attractive but are incompatible with actions already taken.

(2) It generally is more costly and more time consuming than the cost estimating relationship method. To have element estimates on a major system which are complete, current with new cost rates and design changes, and internally consistent can be a large assignment. Great care is warranted in avoiding excessive details; i.e., those whose impact on the system will be minor.

(3) It is potentially difficult to review and evaluate. There could be a tendency for cost models prepared by the engineered cost estimate method to become so large, complex, and detailed that they cannot be interpreted and compared within the time and resources available. Again, avoidance of low-impact details, as well as advance establishment of rules and procedures for element estimate summarization and verification, is essential if this pitfall is to be avoided.

(4) It is subjective in some cost inputs, and the effect of the subjectivity on reliability of subtotals and totals may be great. This drawback calls for careful review and credibility assessment. Best of all, when possible, acquisition strategy and contractual terms should be used to minimize biased inputs and generate credibility.

(5) The Department of Defense is not able always to build its own independent estimate by the engineered cost estimate method. It must settle often for review of the estimates of potential contractors by comparing them with results from the cost estimating relationship method.

8-5.2.3 Consequential Costs (Ref. 11)

The impact of a cost of ownership analysis is that its use sometimes will lead to a preference for a different decision than the one that would have been made if cost consideration were limited to initial costs.

The cost of ownership value, as estimated at any point during the acquisition process, may indicate that the total cost of the contemplated system is excessive in relation to the anticipated benefits. In such cases, the cost of ownership consideration may lead to a program discontinuance, reduction, simplification, or replacement by an alternative approach.

A second .type of impact is shown in Fig. 8-5, which illustrates a case wherein alternative

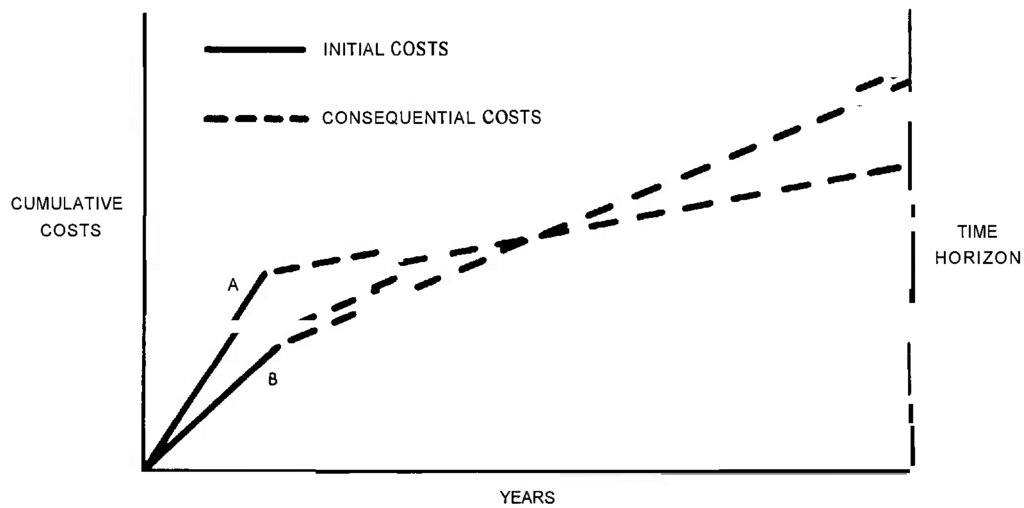


Figure 8-5. Cumulation of Costs Over Time

A, with a higher initial cost than alternative B, leads to a flow of subsequent or "consequential" costs, which are sufficiently smaller, so that the total cost of alternative A is lower than that of alternative B.

On the assumption that the benefits from both alternatives A and B are equal, use of the cost of ownership approach will lead to the choice of alternative A for the "time horizon" shown, whereas without this approach, the choice would be alternative B. However, the choice of a higher initial cost item sometimes may be constrained by short-term budgetary limitations, or by other considerations; e.g., manpower, real estate, or investment policies. In such cases, when it appears that the full advantage of the total cost of ownership approach cannot be achieved within these constraints, the policy authority should be advised so that he may be afforded an opportunity to remove the constraint.

Selection of the time horizon (economic life) can be a critical element of the total life cycle cost decision process. This selection should be made carefully in each application, based on the expected or intended life or lives of the alternatives under consideration. The choice of the "time horizon" will determine whether the cumulative cost lines cross during or after that life (if they cross at all). Equally important, the time horizon also influences the quantitative differences among the total cost of ownership values.

The economic lives of the alternatives govern the time period to be covered by a cost of ownership analysis. The period should be set so that the alternatives start yielding the benefits in the same year. The analysis should be made, using the same base year for all alternatives. That is,the first year in which expenditures will have to be made for any one of the alternatives should be considered the base year or "project year 1" for all the alternatives. For example, it is possible for alternative A to require investment costs for 3 yr before becoming fully effective, while alternative B may become operational after only 2 yr of investment. In this case, the base for alternativeA is used as the starting year for both, and alternative B has zero costs for that year. This imposes an appropriate opportunity cost for the capital required to finance the alternative that requires earlier funding (lead-time).

There can be cases when economic life equality cannot be established. In these cases, a uniform annual cost should be calculated. This cost is obtained by dividing the total present value cost by the sum of the present value factors of the years in which an alternative yields benefits. This gives the average cost per year of production. The alternative with the smallest average cost per year of production is considered to be the most efficient alternative. Refer to par. **8-5.2.4.1** relative to discounting.

8-5.2.4 Cost Models

The most common analytical tool used to conduct total cost of ownership analysis is the cost model. A cost model comprises one or more mathematical relationships, arranged in a systematic sequence to formulate a cost methodology in which outputs (cost estimates) are derived from inputs (descriptions of the equipment, organization, procedures, etc.). Cost models can vary from a simple one-formula model to an extremely complex model that involves hundreds or even many thousands of calculations. As an example of a very simple cost model, the cost of an item might be related directly to its weight, i.e.,

$$C = DW \tag{8-1}$$

where

C = cost of item in dollars

D = cost in dollars per pound of weight

W = weight in pounds.

Here, D and W are inputs to the model, and C is the output. Although this is a very simple model, it nevertheless performs the function of providing a cost estimate for given inputs.

Because the term "cost model" is used in various situations, it can have a variety of specific meanings. In all cases, it is a device designed to obtain a cost estimate. In brief, it is more or less an abstract representation of a part of the real world based upon insights into the cause-and-effect relationships existing in that world.

There are various kinds of cost models. Cost of ownership models are distinguished from other cost models, in that they always reflect subsequent costs which are the direct consequence of the decision or action being contemplated, including operating and support costs, rather than merely the initial costs. For example, in Fig. 8-5, a cost of ownership model estimates the sum of the initial costs (solid line) and the consequential costs (dashed line), whereas most other models estimate only the initial costs.

Cost models are structured to conform to specific categories, depending upon their intended use. Examples of these categories include breakdowns by organizational entities, program elements (5-yr defense program), specific budget categories, functional elements, work breakdown structure (hardware applications), and special categories relating to investment decisions.

The cost of ownership analysis used for making a particular decision, such as source selection or a design choice, need not include the total identifiable costs for the system. For instance, costs which would be the same for each alternative, costs incurred prior to the decision (sunk costs), and costs which would be too small to affect the decision need not be included.

Care must be used in the choice of costs to be excluded lest their omission would improperly influence the decisions to be made. For example, consider the case of procuring a relatively inexpensive payload launched by a large field artillery booster rocket. It would be tempting to exclude launch vehicle costs because they appear to be common to competing payloads. This would restrict the cost analysis to the trade-off between the costs and the reliability of competing payloads. Exclusion of launch vehicle costs could lead to selection of a cheaper, less reliable payload. But the lower reliabilities of cheaper payloads could generate requirements for a larger quantity of boosters. Thus, the assumption on which the field artillery booster rocket costs were excluded would prove to be invalid.

Recently, a Joint Industry Association/Department of Defense Working Group completed work on a comprehensive cost of ownership model (Ref. 11). A version of that model and a description of the input factors follow.

The overall equation for total system cost of ownership may be thought of in terms of two parts:

$$LCC_T = LCC_D + LCC_E \qquad (8\text{-}2)$$

where

LCC_T = total life cycle cost

LCC_D = that portion of LCC which is relevant to the decisions under consideration

LCC_E = that portion of LCC which is excluded in reaching the specific decision; e.g., insignificant costs, sunk costs, and costs that are identical for the alternatives under consideration.

Costs which are relevant to most applications of cost of ownership analysis are represented by LCC_D, and can be identified further as:

$$LCC_D = B + C \qquad (8\text{-}3)$$

where

B = bid or contract price

C = cost to the Government of the consequences of selecting the contractor.

Bid or contract price B represents money expected to be paid to the contractor. Consequential costs C are future costs of ownership incurred by the Government in connection with materiel produced by the contractor. Costs B result from requirements for performance, reliability, maintainability, etc., and are nonrecurring. Costs C result from support resource requirements, and are recurring. Maintenance engineering's goal is to minimize the total of costs B and costs C by establishing design features that permit economical support and optimizing the manner in which the support is provided.

In the calculation of costs C for the various alternatives, maintenance engineering determines resource requirements, and, depending upon the local situation, either may perform the calculations or give the requirements to some other function, such as Finance, for costing. In either event, it is important for maintenance engineering to be knowledgeable of the cost categories considered under costs C, which include:

a. Operational personnel and consumables cost

(1) Personnel

(2) Consumables

b. Training costs

(1) Initial and replacement training

(2) Recurring training

c. Maintenance costs

(1) Organizational

(2) Field

(3) Depot (system level)

(4) Depot (subsystem or component level)

d. Facilities

e. Initial Government materiel and services

f. Support and test equipment

g. Data

h. Initial repair parts

i. Salvage and disposal

j. Initial and replacement transportation

k. Supply management.

8-5.2.4.1 *Discounting*

Before discussing explicit cost of ownership equations, certain principles of economic analysis must be understood since they appear as terms in the equations. Three major precepts are involved: economic life, present value (discounting), and inflation. Economic life was covered previously in the discussion of time horizons (par. 8-5.2.3).

In every investment, explicit recognition should be given to the fact that a dollar today is worth more than a dollar tomorrow because of the interest cost which is related to all Government expenditures which occur over time. Thus, an annual savings or cash inflow projected for tomorrow has a present value less than its undiscounted dollar value. Dollar benefits which accrue in the future cannot be compared directly with investments made in the present because of this time value of money. Discounting is a technique for converting various cash flows occurring over time to equivalent amounts at a common point in time—considering the time value of money—to facilitate a valid comparison. Current DoD Instructions (Ref. 12) require discounting to be accomplished in virtually all economic analyses. The use of a discount rate of 10 percent is currently specified, but this rate will vary with national economic trends. Ref. 12 provides a unique discount factor for each future year to be used when accomplishing discounting at a 10% rate.

Discounted cash flows and the attendant aspects of economic analysis may tend to substantiate and provide clearer and more complete justification for proposed investment projects. Discounting is a small but significant aspect of an economic analysis. That is, a discounted cash-flow analysis may have a critical effect on the alternative choice decisions, changing the results of an analysis from what they would have been if undiscounted costs had been used. However, it should be noted that discounting does not always change the alternative choice decisions. Discounting will demonstrate whether or not decisions that might be reached using only undiscounted costs are, in fact, valid. Discounting will also provide a better indication of the cost savings to be realized from a cost reduction investment proposal.

The degree of change in the relative cost of alternatives is influenced primarily by four factors:

a. The Economic Life. Discounting makes a bigger difference the longer the economic life.

b. The Discount Rate. The higher the discount rate the larger is its impact.

c. The Inczdence of Costs. An alternative with high costs in early years and lower costs later will appear less favorable, discounted, than an alternative with relatively lower initial costs.

d. The Reliability of Cost Estimates. The accuracy and adequacy of cost estimates represent an important factor in a discounted cash-flow analysis.

The discounting technique represents an additional tool that should be applied during the cost of ownership analysis. This technique most likely will not be the most important analytic technique used in making an economic analysis, nor should it be relied upon heavily to identify the most economical investment alternatives. For example, an investment proposal may involve long-range cash-flow projections which are subject to a high degree of uncertainty. This may be the case for certain weapon systems and research projects.

Inflation also is a factor in cost of ownership analysis. Estimates for inflation continuing into future years often are important in conducting time-phased trade-off studies and analyses. When this is the case, analyses and evaluations should consider inflation specifically. To detect the effect of changes in the purchasing power of a dollar, both constant dollars (without inflation) and current dollars (with inflation) should be considered in analyzing and evaluating alternatives. To assure consistency in comparative analyses, all estimates of costs and financial benefits for each year of the planning period should first be made in terms of constant dollars, i.e., in terms of the general purchasing power of the dollar at the time of decision. These estimates should not include any forecast change in the general price level during the planning period.

When inflation is considered important to the conclusion of the analysis, a second computation will be made in terms of current dollars (with inflation). By use of the constant dollar estimates as a baseline, inflation should then be included, either by using price indices or, as a last resort, by application of a uniform inflation rate. When there is reason to believe that price levels (e.g., for procurement, research, development, test, and engineering) will significantly affect the choice between alternatives, factors available for these categories should be used. Indices promulgated by the Office of the Assistant Secretary of Defense (Comptroller) for use in escalating cost estimates in annual budget submissions should be used as appropriate.

Three methods can be used to calculate program/project costs adjusted for inflation: (1) inflate the cost streams first and then introduce the discount rate; (2) discount the cost streams first and then introduce inflation; and (3) apply a joint discount/inflation rate in a single calculation. The first method is preferred because it portrays changes in real prices exclusive of the effects of discounting.

8-5.2.4.2 Explicit Equations

Calculation of some consequential costs is rather involved, while others, such as facility costs, may be calculated in a straightforward manner. Equations for the more involved calculations are described in the paragraphs that follow, and a general equation is given for the accomplishment of other calculations.

a. Cost of Operating Personnel. The cost of operating personnel COP for the life of the system, discounted to present value by the discount factor D_k, is the sum of the annual discounted costs. The annual costs are in turn the sums of costs for each personnel type, skill, and level. The annual cost for each personnel type is the product of the personnel quantity PR_{sjk} for each skill, type, and year, and the annual cost per person CP_{sjk} for that skill, type, and year. The following formula is the general form used to compute COP.

$$COP = \sum_{k=1}^{Y} D_k \sum_{j=1}^{NT} \sum_{s=1}^{NS} (PR_{sjk})(CP_{sjk}) \tag{8-4}$$

where

Y = number of years

NT = number of personnel types

NS = number of skills and levels

b. Cost of Operating Consumables. The cost of operating consumables COC is determined from a list of consumables numbered from 1 to NC, the rate of consumption in units per hour RC_i for each consumable, the cost per unit CUC_i of each, and the number of hours HC_{ik} each year that each consumable is to be used. These consumables consist of items such as gasoline, fuel oils, and electrical power to the extent that consumption can be estimated. The computational equation is as follows:

$$COC = \sum_{k=1}^{Y} D_k \sum_{i=1}^{NC} (RC_i)(CUC_i)(HC_{ik}) \tag{8-5}$$

c. Cost of Training. Cost of training is the sum of the cost of initial training *CIT* and the cost of recurring training *CRT*. It consists of personnel Military Occupational Speciality (MOS) training as defined by succeeding equations and factors.

(1) *Cost of Initial Training.* Cost of initial training *CIT* consists basically of the per person cost of initial training CI_{sjk} multiplied by the number of personnel to be trained in each type *NT* and skill and level *NS* for each year *Y*. When system deployment is to be accomplished all in one year, the problem is somewhat simplified. When deployment and training are accomplished over a number of years, however, the number of personnel to be trained in any given year is determined from the total number PR_{sjk} in each skill, level, and type required by the deployed systems during that year minus the number of personnel PF_{sjk} already available and fully trained during previous years. The total cost for each year is computed, discounted by the factor D_k, and summed to produce *CIT*.

$$CIT = \sum_{k=1}^{Y} D_k \sum_{j=1}^{NT} \sum_{s=1}^{NS} (CI_{sjk})(PR_{sjk} - PF_{sjk}) \qquad (8\text{-}6)$$

(2) *Cost of Initial Training Per Person.* Cost of initial training per person CI_{sjk} is determined as the product of the number of weeks TNW_{sj} of training required for each skill level and personnel type, and the training cost per week CPW_{sjk} for the year in which the training is to be accomplished. (For simplicity, CPW_{sjk} may be given as one value for all officers, another for all enlisted men, and another for civilians.)

$$CI_{sjk} = (TNW_{sj})(CPW_{sjk}) \qquad (8\text{-}7)$$

(3) *Cost of Recurring Training.* Cost of recurring training *CRT* is defined as the cost of training replacement personnel required as a result of personnel attrition. It is determined by summing the discounted product of the total personnel PR_{sjk} in each skill level and type required by the deployed system in a given year, the personnel attrition rate RT_{sj} for each skill level and type, and the per person cost of recurring training CR_{sjk}. The last factor CR_{sjk} is assumed to be the same as the cost per person of initial training CI_{sjk} given in subpar. (2), unless otherwise specified.

$$CRT = \sum_{k=1}^{Y} D_k \sum_{j=1}^{NT} \sum_{s=1}^{NS} (CR_{sjk})(RT_{sj})(PR_{sjk}) \qquad (8\text{-}8)$$

d. Cost of Maintenance. Cost of maintenance *MC* for the total number of line items over the system life is the sum of the cost of maintenance at the organization level *CMO* excluding operator maintenance, the cost of maintenance at field level *CMI,* the cost of system overhaul at depot level *COD,* the cost of component maintenance at depot level *CMD,* and the cost of maintenance consumables *CCM,* including discard-at-failure repair parts. Multiplying this value by the ratio of the total number of recoverable line items *NO* in the system to the total number of recoverable line items identified at the time of the estimate *NR* will yield a projected estimate of the total system maintenance cost.

$$MC = (CMO + CMI + COD + CMD + CCM)\left(\frac{NO}{NR}\right) \qquad (8\text{-}9)$$

(1) *Cost of Maintenance at Organizational Level.* The cost of maintenance at the organizational level *CMO* is computed on a repairable item basis, and is the product of the total maintenance man-hours per year HO_i for all deployed systems for each item and the per man-hour cost of maintenance labor at the organizational level CLO_k by year. Maintenance labor man-hours include maintenance performed by maintenance personnel organic to the using unit, but specifically exclude maintenance performed by operators, since operator cost is included in *COP*. HO_i is the product of the number of organizational man-hours per maintenance operation, the item maintenance factor, the percent repaired at organizational level, the quantity of like items per system *NR,* and the total number of systems deployed.

$$CMO = \sum_{k=1}^{Y} D_k \sum_{i=1}^{NR} (HO_i)(CLO_k) \qquad (8\text{-}10)$$

(2) *Cost of Maintenance at Field Level.* The cost of maintenance at field level *CMI* (direct and general support) is the sum of the discounted annual repair labor cost at the field level. The cost of field maintenance labor is computed on a repairable item basis as the product of the maintenance man-hours per year HI_i for each item and the per man-hour labor cost at the field level CLI_k. HI_i is the product of the number of field maintenance man-hours per maintenance operation, the item maintenance factor, the percent repaired at field level, the quantity of like items per system, and the total number of systems deployed.

$$CMI = \sum_{k=1}^{Y} D_k \sum_{i=1}^{NR} (HI_i)(CLI_k) \qquad (8\text{-}11)$$

(3) *Cost of System Overhaul at Depot.* Cost of system overhaul at depot *COD* is determined by the number of operational systems *NOU,* divided by the number of months between operational system overhauls *MOD,* plus the number of training and other nonoperational systems *NTU,* divided by the number of months *MTD* between overhaul of these nonoperational systems, all multiplied by *12* months (to convert to an annual basis) and by the cost per system overhaul at the depot *COH.* The cost per overhaul, including labor and transportation, must be estimated or computed on a system level basis.

$$COD = \sum_{k=1}^{Y} (12D_k)(NOU/MOD + NTU/MTD)_k(COH) \qquad (8\text{-}12)$$

(4) Cost of Subsystem and Component Maintenance at Depot. Cost of subsystem and component maintenance at depot *CMD* is the sum of the discounted annual maintenance repair labor costs. The annual repair labor cost at depot level for subsystem and component repair is the summation of the annual repair labor costs for each listed repairable item, which is computed as the product of the annual depot repair maintenance labor man-hours HD_i for each item and the per maohour cost of labor at depot level CLD_k. HD_i is the product of the number of depot maintenance man-hours per maintenance operation, the item maintenance factor, the percent repaired at depot level, the quantity of like items per system, and the total number of systems deployed.

$$CMD = \sum_{k=1}^{Y} D_k \sum_{i=1}^{NR} (HD_i)(CLD_k) \qquad (8\text{-}13)$$

(5) Cost of Maintenance Consumables. Cost of maintenang consumables *CCM,* including nonrepairable and discard-at-failure repair parts, is computed indirectly from the cost of initial issue repairable item inventory ***CIR,*** the average requirements objective period ***ROP*** in years on which the initial issue inventory is based, and the estimated distribution of repairable items (high-cost contributors) and nonrepairable items (generally low-cost contributors). For initial estimates, it is assumed the repairable items contribute 85 percent of the inventory cost and nonrepairable items contribute the remaining *15* percent of the inventory cost. The value ***CIR/*0.85** projects an estimate of the total cost of the repair part inventory, including consumables. Multiplying by *0.15* determines an estimate of the inventory cost of consumables. Dividing the result by the average ***ROP*** in years and multiplying by ***NO/NR*** results in an estimate of the cost of annual 'consumption of consumables. **A** summation of the discounted annual costs for the life of the system yields the cost of maintenance consumables.

$$CCM = \sum_{k=1}^{Y} D_k \left[\frac{(CIR)(0.15)}{(0.85)(ROP)}\right]\left(\frac{NO}{NR}\right) \qquad (8\text{-}14)$$

e. Miscellaneous Cost Categories. Miscellaneous costs *MSC* which may be required in certain cases, and which are not included in the foregoing equations, include items such as support of special maintenance, training, supply, etc., facilities *FAC,* peculiar Government furnished material or services *GMS,* the cost of printing and distributing management and technical data *DTA,* and the cost per year of new supply item management *SMG.*

$$MSC = FAC + GMS + DTA + SMG \qquad (8\text{-}15)$$

8-5.2.4.3 ***Short Form Equations***

For iteration purposes, it is generally advantageous to group personnel types and skills and use an average cost per man, or to group repairable items and use average man-hours, maintenance factors, etc., in order to obtain faster computational turnaround. It is also convenient and, in most cases, reasonably accurate to assume a constant annual cost and compute the discounted (present value) life cost, using a cumulative discount rate DC_Y furnished by the Department of Defense.

The following short-form equations are given for that purpose, and may be substituted for corresponding equations.

Operating personnel *COP:*

$$COP = (DC_Y)(PR_T)(CP_A) \tag{8-16}$$

Operating consumables COC:

$$COC = (DC_Y) \sum_{i=1}^{NC} (RD_i)(CUC_i)(HC_{ik}) \tag{8-17}$$

Initial training *CIT* (MOS training):

$$CIT = \sum_{k=1}^{Y} (D_k)(PT_k)(CI_A) \tag{8-18}$$

Recurring training *CRT* (MOS training):

$$CRT = (DC_Y)(PR_T)(RT_A)(CR_A) \tag{8-19}$$

Organizational maintenance *CMO:*

$$CMO = (DC_Y)(NR)(HO_A)(CLO_k) \tag{8-20}$$

Cost of maintenance at intermediate *CMI*:

$$CMI = (DC_Y)(NR)(HI_A)(CLI_A) \tag{8-21}$$

Cost of system overhaul at depot *COD:*

$$COD = 12DC_Y(NOU/MOD + NTU/MTD)(COH) \tag{8-22}$$

Cost of subsystem and component maintenance at depot *CMD:*

$$CMD = (DC_Y)(NR)(HD_A)(CLD_A) \tag{8-23}$$

The definitions of the terms used in Eqs. **8-16** through **8-23** that were not identified previously are:

CI_A = average initial MOS training cost per person, all skills, types, and years

CLD_A = average cost of labor at depot, per man-hour of maintenance, over system life

CLI_A = average cost of labor at intermediate, per man-hour of maintenance, over system life

CP_A = average annual cost per person, all types, skills, and years

CR_A = average cost of replacement MOS training per person, all skills, types, and years

HD_A = average annual maintenance man-hours at depot, all items

HI_A = average maintenance man-hours at intermediate, all items

HO_A = average annual maintenance man-hours at organization, all items

PT_k = total quantity of O&M personnel trained in year k

PR_T = total quantity of O&M personnel required to man deployed systems

RT_A = average personnel attrition rate

8-5.2.4.4 Model Application

The cost of ownership model discussed previously can be very effective in developing preliminary cost estimates when historical data are available. A brief discussion of calculation methodology and a hypothetical example of one equation are included to illustrate the type of cost estimates that can be generated. Since one of the major ownership cost factors is operating personnel, that equation has been chosen for explanation.

The calculation methodology for cost of personnel is shown in Table 8-7.

The example in Table 8-7 illustrates the effect **of** cost of personnel on the life cycle cost of ownership of a weapon or system. The other cost model equations can also be exercised, using historical and predicted data and similar results obtained. When the costs are summed, it is not unusual for a modern weapon system 10-year post-deployment cost of ownership to exceed $1 billion.

As stated previously, maintenance engineering activities can have a major influence on the total cost of ownership of Army materiel. The accuracy of maintenance support guidance and the thoroughness of maintenance engineering analyses both impact key decisions that affect these categories of cost.

TABLE 8-7. PERSONNEL COST CALCULATION (Ref. 11)

Note: Eq. 8-4 is solved in the following manner to determine the cost of operating personnel.

$$COP = \sum_{k=1}^{Y} D_k \sum_{j=1}^{NT} \sum_{s=1}^{NS} (PR_{sjk})(CP_{sjk})$$

(a) Multiply the number of men PR of skill and level 1 ($s = 1$), type 1 ($j = 1$), required in year 1 ($k = 1$), by the annual cost CP of such men.

(b) Repeat (a) for each of the othr skills and levels ($s = 2, 3, \ldots NS$) of type 1 ($j = 1$), and add the results to the result of (a). The result is the total cost of operating personnel of all skills and levels, of type 1 ($j = 1$), in year 1 ($k = 1$).

(c) Repeat (a) and (b) for each of the other types of operating personnel ($j = 2, 3, \ldots NT$), and add the results to the result of (b). The result is the total cost of operating personnel of all types (civilian, military, . . .), and all skills and levels (pilot, navigator, etc.; lieutenant, . . . , captain, etc.) in each type, for year 1 ($k = 1$).

(d) Multiply the total personnel cost of year 1 by the discount factor D_k for year 1 ($k = 1$). Now we have the present value of the total cost of operating personnel for year 1 ($k = 1$).

(e) Repeat (a) through (d) for each of the subsequent years ($k = 2, 3, \ldots Y$), and add the results to the result of (d). The result is the total cost of operating personnel, over the life cycle of the system (Y years), all discounted to a present value.

The solution procedure is applied to a problem as follows:

A. Background information is as follows:

1. The hardware involved is a personnel transport helicopter.
2. Two units are assigned per base.
3. There are 50 bases worldwide.
4. There are two operators per vehicle.

	Annual Cost
One pilot per vehicle (military)	$25,000
One copilot/engineer per vehicle (military)	$22,000

TABLE 8-7. PERSONNEL COST CALCULATION (Cont'd)

5. There are two ground service personnel per vehicle

	Annual Cost
One leadman per vehicle (military)	$15,500
One attendant per vehicle (civilian)	$10,500

6. 10 yr operating life for the helicopter
7. Items 2 through 5 apply for each of the 10 yr of operation.

B. The actual calculation of cost of operating personnel is as follows:

1. Indices

Number of types of personnel	$NT = 2$
Military	$j = 1$
Civilian	$j = 2$
3 Military skill levels	$NS = 3$
Pilot	$s = 1$
Copilot	$s = 2$
Ground service leadman	$s = 3$
1 Civilian skill level	$NS = 1$
Ground service attendant	$s = 1$
Operating years	$Y = 10$
Incremental years	$k = 1, 2, \ldots 10$

2. Calculations

(Total vehicles worldwide = 50 × 2 = 100)

$j = 1$, all military types; $k = 1$, in year 1

$s = 1$, cost of pilots: $(PR_{1,1,1})\ (CP_{1,1})$

(1 pilot per vehicle × 100 vehicles)
(25,000 per pilot) = $2,500,000

$s = 2$, cost of copilots: $(PR_{2,1,1})\ (CP_{2,1})$

(1 × 100) (22,000) = $2,200,000

$s = 3$, cost of ground service leadman: $(PR_{3,1,1})\ (CP_{3,1})$

(1 × 100) (15,500) = $1,550,000

Subtotal $6,250,000

$j = 2$, all civilian types

$s = 1$, cost of ground service attendant: $(PR_{1,2,1})(CP_{1,2})$

(1 × 100) (10,500) = $1,050,000

Subtotal $1,050,000

Total cost of operational personnel in year 1 $7,300,000

Discount the total cost of year 1 at a rate of 10 percent. Obtain discount factor (D_k) for year 1 and subsequent years from Ref 12.

TABLE 8-7. PERSONNEL COST CALCULATION (Cont'd)

Year	Total Cost in Year k		Discount Factor for Year k		Present Value of Cost in Year k
$k = 1$	$\sum_{j=1}^{NT} \sum_{s=1}^{NS} (PR_{sjk})(CP_{sjk})$		(D_k)	=	COP subtotal
1	$7,300,000	X	0.954	=	$6,964,200
(Repeat foregoing calculation for years 2 through 10.)					
2	$7,300,000	X	0.867	=	$6,329,100
3	$7,300,000	X	0.788	=	$5,752,400
4	$7,300,000	X	0.717	=	$5,234,100
5	$7,300,000	X	0.652	=	$4,759,600
6	$7,300,000	X	0.592	=	$4,321,600
7	$7,300,000	X	0.538	=	$3,927,400
8	$7,300,000	X	0.489	=	$3,569,700
9	$7,300,000	X	0.445	=	$3,248,500
10	$7,300,000	X	0.405	=	$2,956,500
	Total life cycle cost of operational personnel, discounted to present value COP			=	$47,063,100

REFERENCES

1. NAVORD OD 39223, *Maintainability Engineering Handbook,* 1 February 1970.
2. AR 750-1, *Army Materiel Maintenance Concepts and Policies,* May 1972.
3. TM 38-750, *The Army Maintenance Management System (TAMMS),* November 1972.
4. MIL-STD-1388-1, *Logistic Support Analysis,* 15 October 1973.
5. DA PAM 701-1-3, *Development and Implementation Digest,* LOGMAP, **Volume 111,** 31 January 1974.
6. AR 750-37, *Sample Data Collection, the Army Maintenance Management System (TAMMS),* **24** March 1971.
7. Ralph R. Tappen, "SPEEDEX: AMC's Information Processing System for Depots", *Army Logistician,* November-December 1972.
8. MIL-STD-1388-2, *Logistic Support Analysis Data Element Definitions,* 15 October 1973.
9. AMCR 750-27, *Maintenance of Supplies and Equipment, AMC Utilization of Maintenance Data, 20* October 1970.
10. DA PAM 700-20, *Test, Measurement and Diagnostic Equipment Register,* 31 December 1973.
11. DoD LCC-3, *Life Cycle Costing Guide for System Acquisitions (Interim),* January, 1973.
12. DoD Inst. 7041.3, *Economic Analysis and Program Evaluation for Resource Management,* 18 October 1972.
13. AMCC 750-2 *Depot Maintenance CCEDR,* 18 July 1973.

BIBLIOGRAPHY

Army Force Planning Cost Handbook, Office, Comptroller of the Army, July 1973.

AFM 173-10, *USAF Cost and Planning Factors,* 1 April 1973.

CHAPTER 9
DIAGNOSIS AND TROUBLESHOOTING

This chupter discusses diugnosis und troubleshooting as they apply to various types of Army materiel and various factors thut affect diagnosis arid troubleshooting. Among these factors are the human factor aspects of diagnosis and troubleshooting, test, measurement, und diagnostic equipment considerutions, and troubleshooting techriiques arid uids.

9-1 INTRODUCTION

The military has formulated several definitions of troubleshooting. Among them are "locating and determining corrective action required to rectify discrepancies or malfunctions of materiel" (Ref. 1), "actions performed to isolate and identify the specific component which caused a malfunction of a system or complex component when the determination could not be made by the operator or mechanic who initially found the discrepancy" (Ref. 1), and "locating and diagnosing malfunctions or breakdowns in equipment by means of systematic checking or analysis" (Ref. 2).

Formal definitions of diagnosis are not available, but it is an inseparable part of troubleshooting, and is considered by most maintenance personnel to be synonymous with the latter. Therefore, in this chapter, diagnosis and troubleshooting are considered to be that portion of the overall corrective maintenance process given to determining what has caused materiel to perform improperly. Simply stated, diagnosis and troubleshooting comprise the actions involved in fault isolation.

With automatic, built-in test equipment, operators can perform in-depth diagnosis and troubleshooting. Otherwise, because of a lack of skill, time, and equipment, operators normally perform only the most elementary types of diagnosis and troubleshooting; i.e., isolating the cause of a loss of power to a burned out fuse. More frequently, the operator reports difficulties to the organizational maintenance activity. Here, and at higher maintenance levels, the majority of diagnosis and troubleshooting is accomplished.

The effectiveness of the diagnosis and troubleshooting process :generally depends upon the maintenance technician's understanding of system or equipment operating theory, and his assessment of its specific malfunctioned condition as determined by a series of tests or measurements of specific performance parameters against prescribed norms or standards. The technician may use only his basic senses of sight, touch, hearing, and smell to make the tests and measurements, but generally uses materiel aids which extend these senses.

For example, a defective bearing in mechanical equipment frequently can be identified by a knocking or pounding sound. On the other hand, identification of a defective part in a radio may require the use of a voltmeter or other device, which enables the technician to determine how well the part is performing. Devices that serve to extend the basic human senses for purposes of enabling system or equipment diagnosis and troubleshooting are referred to as items of test, measurement, and diagnostic equipment (TMDE).

9-1.1 THE DIAGNOSIS AND TROUBLESHOOTING PROCESS

The overall diagnosis and troubleshooting process can be divided, into three basic segments, regardless of the function a system or equipment performs. These segments are symptom identification, malfunction localization, and malfunction isolation.

9-1.1.1 Symptom Identification

Equally important to any other event in the overall diagnosis and troubleshooting task is the assessment of those operating symptoms or anomalies that have caused the person reporting a malfunction to believe that a malfunction actually exists. When possible, it is preferred that the repair technician personally discuss the reported malfunction with the person reporting it. Answers to questions such as "Is the malfunction continuous or intermittent?", "Are all operating modes affected?", "Is performance totally unacceptable or only marginal?", "Has correction been attempted?", and "When did the malfunction occur?" provide the technician with valuable insight into the specific nature of the malfunction and tend to "set the stage" for his subsequent diagnosis and troubleshooting actions.

Unfortunately, items requiring maintenance of other than the most routine nature typically are sent from the using organization to a unit specifically equipped and responsible for detailed maintenance. In such cases, the repair technician normally cannot discuss the reported malfunction personally with the reporting individual, but must rely instead upon a maintenance request form, trouble report, or other such documentation accompanying the malfunctioning item to the repair facility. Fig. 9-1 provides an example of a typical maintenance request form used by the Army.

Section I of the example form provides the repair technician with a description of the abnormal symptoms as observed by the using unit, together with an indication of the corrective measures, if any, that already have been attempted. (Section 11–Work Accomplished–is completed by the repair organization/activity upon performance of the maintenance.) In the example, the channel selection mode of a radio transmitter operates improperly. Improper operation was detected during normal use with the transmitter "on", and correction attempts by the user have not been successful. It should be noted in this example that a most fundamental form of diagnosis and troubleshooting already has been performed. In accordance with procedures set forth in the transmitter technical manual, certain tubes in the transmitter were checked by the user and found to be good. This process entailed the use of TMDE in the form of an electronic tube tester.

At this point in the diagnosis and troubleshooting process, the technician has become aware of a number of symptoms related to the transmitter malfunction example. Summarized, they are:

a. Selection of preset frequencies is not possible.

b. The malfunction was detected during normal use, rather than following some period of nonuse.

c. The user has attempted correction unsuccessfully by using a simplified "symptom/probable cause" tabulation contained in the user technical manual.

Armed with the preceding information, the technician is prepared to begin the malfunction localization segment of the diagnosis and troubleshooting process.

9-1.1.2 Malfunction localization

The localization of a malfunction within materiel entails the assessment and analysis of reported symptoms and the results of selected tests and measurements. During this segment, the technician assembles the information available to him thus far, and, through a logical process, attempts to identify a pattern of indications that direct his attention to a selected portion or section of the malfunctioned equipment.

In the case of the transmitter malfunction example, after verification of previous test results the technician is able to deduce logically that because preset frequencies cannot be selected, and tests of tubes associated with the selection mode do not locate the malfunction, probably the trouble lies elsewhere in the equipment.

Assuming a transmitter arrangement such as that depicted by Fig. **9-2,** the technician can establish basic transmitter operation quickly by checking for a proper energy level at the output of the power amplifier (circuit test point **1**). Upon making this test using a power meter or other item of TMDE, the technician finds that the energy level at this point is abnormally low. Since the power amplifier requires a proper input to yield a proper output, he next measures the output of the amplifier/modulator at circuit test point **2.** This output level also is found to be abnormally low.

The basic input to the amplifier/modulator is provided by the oscillator, whose output appears at circuit test point **3.** A check reveals this level to be normal.

MAINTENANCE REQUEST
For use of this form, see TM 38-750; the proponent agency is Office of the Deputy Chief of Staff for Logistics.

* See reverse of file copy for codes and additional data.

PAGE NO. | NO. OF PAGES | REPORTS CONTROL SYMBOL CSGLD 1047 (R1)

SECTION I ☐ WORK REQUEST ☐ MWO ☐ EIR [5] ORGANIZATION ISSUE PRIORITY DESIGNATOR CODE

CONTROL NUMBER	1a. ORGANIZATION	b. LOCATION	c. UNIT IDEN CODE
831022	1ST BN 66TH INF 21ST INF DIV	APO NY 09372	WAZ CAA

2. SERIAL NUMBER	3. NOUN NOMENCLATURE	4. LINE NUMBER	5. MODEL	6. NATIONAL STOCK NUMBER
1643	TRANSMITTER		T195/GRC19	5820-503-3428

7. MAINTENANCE ACTIVITY	8. UTILIZATION CODE*	9. SELECTED ITEM	10. HOURS	11. MILES	12. ROUNDS	13. STARTS
	M	[1] YES [X 2] NO				

14. FAILURE DETECTED DURING *(Select one - use ✓ or X)*
[A] SCHEDULED MAINTENANCE [C] TEST [E] STORAGE [G] FLIGHT
[B] HANDLING [X D] NORMAL OPERATION [F] INSPECTION [H] OTHER

15. FIRST INDICATION OF TROUBLE *(Select one - use ✓ or X)*
[X 068] INOPERATIVE [258] OVERHEATING [790] OUT OF ADJUSTMENT
[008] NOISY [387] LOW PERFORMANCE [ ] OTHER

16. DESCRIBE DEFICIENCIES OR SYMPTOMS ON THE BASIS OF COMPLETE CHECKOUT AND DIAGNOSTIC PROCEDURE IN EQUIPMENT TM *(Do not prescribe repairs)*

T195 WILL NOT CHANNEL WHEN THE HAND SELECTOR SWITCH IS TURNED TO ANY PRESET FREQUENCIES. CHECKED TUBES V-101, V-102, AND V-103 IN ACCORDANCE WITH THE PROCEDURES IN TM 11-5820-295-20. NSN 5820-00-030-0155

SECTION II - WORK ACCOMPLISHED

17a. REPAIR ORGANIZATION/ACTIVITY | c. UNIT IDEN CODE | 18. TYPE ORGANIZATION/ACTIVITY ACCOMPLISHING WORK *(Select one-use ✓ or X)* [1] TOE TD [3] CONTRACTOR | 19. AMS ACT. CODE

b. LOCATION

20a. ACTION CODE	b. FAILURE CODE*	c. COMPONENT/PART NOUN, SERVICE, OR MWO NO. / d. CB CODE	e. REFERENCE DESIGNATOR	f. MFR. CODE	g. MANHOURS* (Hours & tenths)	h. NATIONAL STOCK NUMBER	i. PART* SOURCE CODE	j. QUANTITY	k. PARTS COST
				l. TOTAL MANHOURS		m. TOTAL MANHOURS COST	n. TOTAL PARTS COST		

21. DELAY *(Select one - use ✓ or X)* [1] PARTS [2] MANPOWER [3] FACILITIES [4] FUNDS [5] TOOLS | 22. ☐ DATA TRANSCRIBED TO LOG BOOK

23. SUBMITTED BY	24. RECEIVED BY	25. WORK STARTED BY	26. INSPECTED BY	27. ACCEPTED BY	28. DISPOSITION *(Select one - use ✓ or X)*
F. POOL					[A] TO USER [B] TO STOCK [C] SALVAGED [D] EVACUATED [E] CANNIBALIZATION
JULIAN DATE 9136	JULIAN DATE	JULIAN DATE	JULIAN DATE	JULIAN DATE	

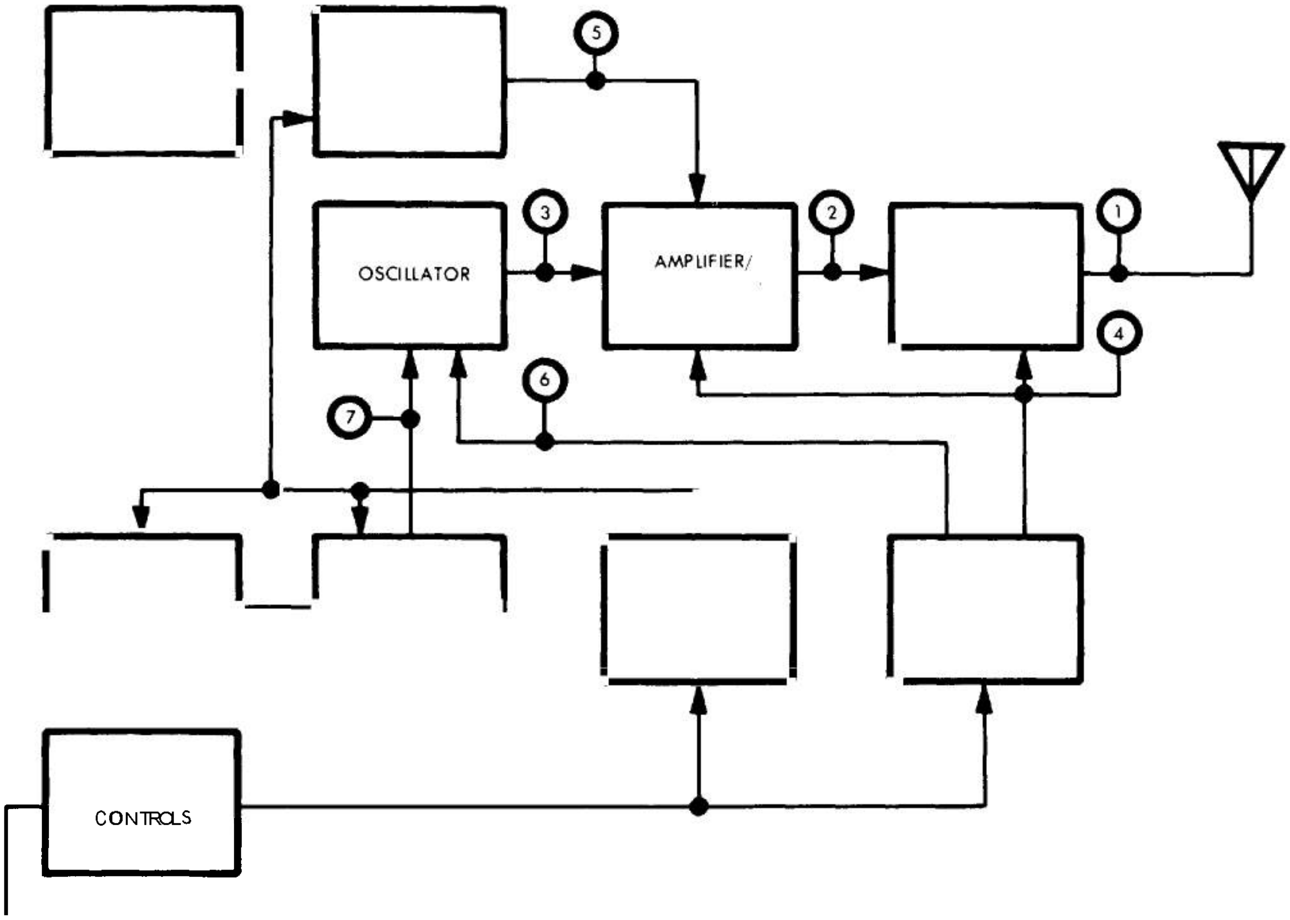
SECTION III - EQUIPMENT IMPROVEMENT RECOMMENDATION

29. NORMAL REPLACEMENT *(Select one - use ✓ or X)* [1] YES [2] NO | 30. EIR *(Select one - use ✓ or X)* [E] EMERGENCY [U] URGENT [R] ROUTINE | 31. RECOMMENDATION *(Select one-use ✓ or X)* [A] IMPROVE DESIGN [B] MODIFY [C] REVISE PROCEDURE [D] OTHER *(Specify)* | 32a. ORGANIZATION/ACTIVITY | c. UNIT IDEN CODE | b. LOCATION | d. SUBMITTED BY

33. NATIONAL STOCK NUMBER | 34. NOUN NOMENCLATURE | 35. OPINION OR REMARKS. DESCRIBE CONDITIONS UNDER WHICH FAILURE OCCURRED. ATTACH PHOTOS OR SKETCHES, IF AVAILABLE.

DA FORM 1 OCT 73 2407 EDITION OF 1 JAN 64 WILL BE USED UNTIL EXHAUSTED. CONTROL COPY 3

Figure 9-1. Maintenance Request Form (Ref. 3)



The technician now knows that both the power amplifier and the amplifier/modulator are operating improperly, and that the primary input to these units from the oscillator is normal. With this information, he is able to determine that the problem is either in the amplifier/modulator, both the amplifier/modulator and the power amplifier, or some other function common to both.

Since the simultaneous occurrence of multiple malfunctions is experienced seldom, he next may test tubes within the amplifier/modulator, or he may check the output of the high-voltage power supply, which is common to both this unit and the power amplifier. In effect, he has localized the malfunction to one of two sources. Because test of the power supply is faster and easier than removal and testing of the amplifier/modulator tubes, he next checks its output at circuit test point **4**. For purposes of this example, we will assume this check to reveal an abnormal indication, thus terminating the fault localization process at the high-voltage power supply unit.

In summary, the technician has started with a statement of abnormal operating symptoms as identified by the person reporting the malfunction, and has verified and used this information in conjunction with the results of selective checks of major equipment functions to localize the malfunction source to a relatively small equipment section. In the process, he has used his knowledge of equipment operating theory and various items of TMDE, the latter serving merely as extensions of his basic senses.

9-1.1.3 Malfunction Isolation

Malfunction isolation represents the final segment of the diagnosis and troubleshooting process. In this segment, the previously localized malfunction is assessed in sufficient detail to establish its specific and precise cause.

In the case of electronic malfunctions, the cause is usually a component part such as a resistor, vacuum tube, transistor, capacitor, or integrated circuit. For mechanical malfunctions, failures of individual items such as bearings, gears, and belts are typical malfunction causes. It is important to note, however, that the actual cause of a malfunction is not necessarily a result of part failure. Misadjustment or misalignment resulting from normal wear or degradation also can result in system or equipment malfunction. Improper valve clearance in a gasoline engine, for example, can cause running roughness or missing. Similarly, an improperly aligned electrical servo system can result in excessive hunting or oscillation.

As noted, malfunction isolation is but the logical extension of the malfunction localization segment of the overall diagnosis and troubleshooting process. It terminates in the identification of a specific malfunction cause, usually a failed part. To illustrate this extension, assume that the transmitter power supply discussed in par. 9-1.1.2 is arranged as depicted in Fig. **9-3.**

In the localization segment, it was established that the output of the power supply was improper at circuit test point **4,** and the output of the oscillator was correct. Using this information, and referring to Fig. **9-3,** it can be seen that tubes V7801 through V7806 and their associated circuit parts are probably the areas in which the malfunction cause lies.

The technician removes and tests each tube, using TMDE in the form of an electronic vacuum tube tester. We will assume that one of these tubes is found to be defective, thus ending the malfunction isolation process by identifying the specific malfunction cause. Another cause, not involving an actual part failure, could have been an incorrect setting of R-7802, resulting from the normal tolerance aging of power supply components.

9-1.2 INFLUENCING FACTORS

The preceding discussion related to the various segments of the diagnosis and troubleshooting process purposely was kept free of distracting side issues. In actual practice, however, a number of factors tend to influence the overall process. These include the governing maintenance concept, built-in troubleshooting features and aids, and TMDE. Other factors having influence include the environment in which diagnosis and troubleshooting are performed, and any special problems that a particular equipment or equipment category may impose. Typical of the latter is the intermittent malfunction in electronic equipment which is caused by temperature. The defective assembly will show some type of abnormal indication only as long as it remains within the equipment case or enclosure. Once the assembly is removed from the equipment configuration for isolation to the individual piece part level it may be exposed to greater ventilation and the defective part is no longer subjected to the degree of temperature that caused its failure.

9-1.2.1 Maintenance Concept

Based upon maintenance engineering analyses, a materiel maintenance concept that is compatible with both the user's mission and existing Army support resources and is effective in terms of life cycle support cost is selected. Relative to the diagnosis and troubleshooting process, the maintenance concept places bounds or limits on the nature and depth of maintenance tasks to be performed at each level of the Army maintenance. These bounds are reflected in the materiel maintenance allocation chart (see par. 4-6.2). Corrective maintenance tasks identified by the chart normally are performed to some degree at every maintenance level and, within each level, each segment (identification, localization, and isolation) of the diagnosis and troubleshooting process is accomplished. The overall complexity of the corrective tasks permitted at a given maintenance level determines the diagnosis and troubleshooting that will be performed and the nature of the support resources necessary to accomplish these tasks.

9-1.2.2 Built-in Troubleshooting Aids and Features

Consistent with the corrective tasks which the maintenance concept relegates to a given maintenance level, the requirements for built-in troubleshooting aids and features are established. If the maintenance concept requires that the user locate and replace a defective chassis,

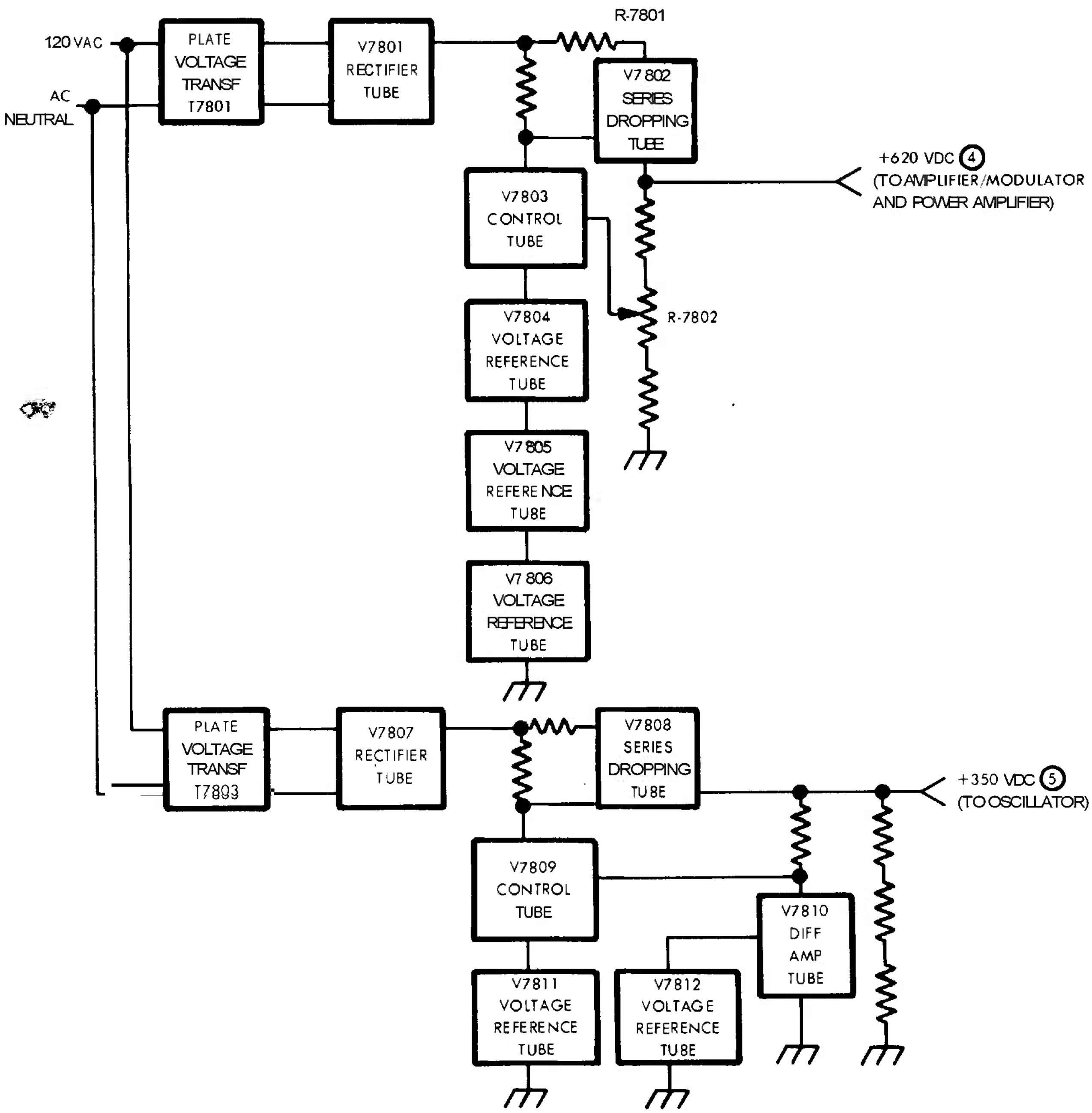


Figure 9-3. Plate Supply, Block Diagram (Ref. 4)

for example, then the system design must incorporate features enabling diagnosis and troubleshooting to the chassis level. These features can assume a variety of forms, depending upon system type and complexity and the amount of time allowed for the overall correction process. In many cases, and particularly at the user level, these features may be the same as those used in initially determining that a malfunction exists. An example is the malfunction of a vehicle electrical system and subsequent detection by the presence of a lighted "charging" indicator. If user maintenance consists of replacing all major charging elements (generator, voltage regulator, etc.) when a malfunction is detected, then the lighted indicator also serves as the built-in diagnosis and troubleshooting aid. If user maintenance consists of replacing only the failed charging element, then additional built-in aids may be required to enable localization and isolation of the failed item. These could take the form of a metering device that monitors selected points in the charging system, or of a series of test points used in conjunction with an external meter or other TMDE. The go/no-go indicator approach can be used whenever it is determined that it is cost-effective to fault isolate automatically to a starter, battery, mechanical device, hydraulic device, etc. For example, a starter may be faulty due to a defective bearing, worn insulation, etc., but may perform its function for a time before catastrophic failure. Such a starter will probably draw an abnormal quantity of current. A built-in current measuring circuit and a fault indicator light can be used for immediate malfunction localization to the starter. With the use of transducers, circuits, and lights, malfunctions related to pressures, temperatures, flow velocities, mechanical rotation, transition and vibration, etc., can be isolated reliably and quickly.

The incorporation of built-in fault isolation capabilities in electrical, electromechanical, hydraulic, mechanical, etc., equipment has lagged the incorporation of such capabilities in electronic equipment. Maintenance engineering should evaluate carefully the cost-effectiveness of making more extensive applications of built-in monitoring equipment in assemblies such as starters, generators, alternators, voltage regulators, batteries, hydraulic systems, etc. The reliability and economy of integrated circuits and solid state components and advances in transducer technology offer built-in monitoring alternatives that did not exist in past years.

Generally speaking, the magnitude and complexity of built-in troubleshooting aids and features are related directly to system complexity and cost-effectiveness. They are designed to provide the maintenance technician with the means to acquire the information he requires for the logical assessment, localization, and isolation of a reported malfunction. This basic purpose of making information available tends to be constant regardless of system function. Fig. 9-4 illustrates functionally similar types of built-in troubleshooting aids and features for functionally dissimilar hydraulic/pneumatic, electrical, and mechanical systems. Each incorporates a test point at which system performance can be assessed by the use of external TMDE, a built-in meter or gage providing a quantitative display of a selected operating parameter, and a built-in error detector and go/no-go malfunction alarm.

For the hydraulic/pneumatic system, a capped tee at the compressor output acts as a test point for use with external TMDE. A pressure gage provides a built-in display of regulator output pressure, and a differential pressure transducer across the filter drives a go/no-go alarm. In the electrical system, a test point is provided for measuring power supply output voltage. A voltmeter provides a built-in measure of regulator output level, and an alarm driven by a differential amplifier provides a gobo-go indication of load balance. A timing mark on the engine of the mechanical system enables measurement of rotational speed by means of external TMDE such as a strobe light, while rotational speed following the reduction gearing is provided by a built-in tachometer. A go/no-go indication of system rotation is provided by an engagement sensor attached to the centrifugal clutch.

9-1.2.3 Test, Measurement, and Diagnostic Equipment (TMDE)

As noted previously, items of TMDE serve to extend the basic human senses for purposes of enabling the diagnosis and troubleshooting process. TMDE is defined as any system or

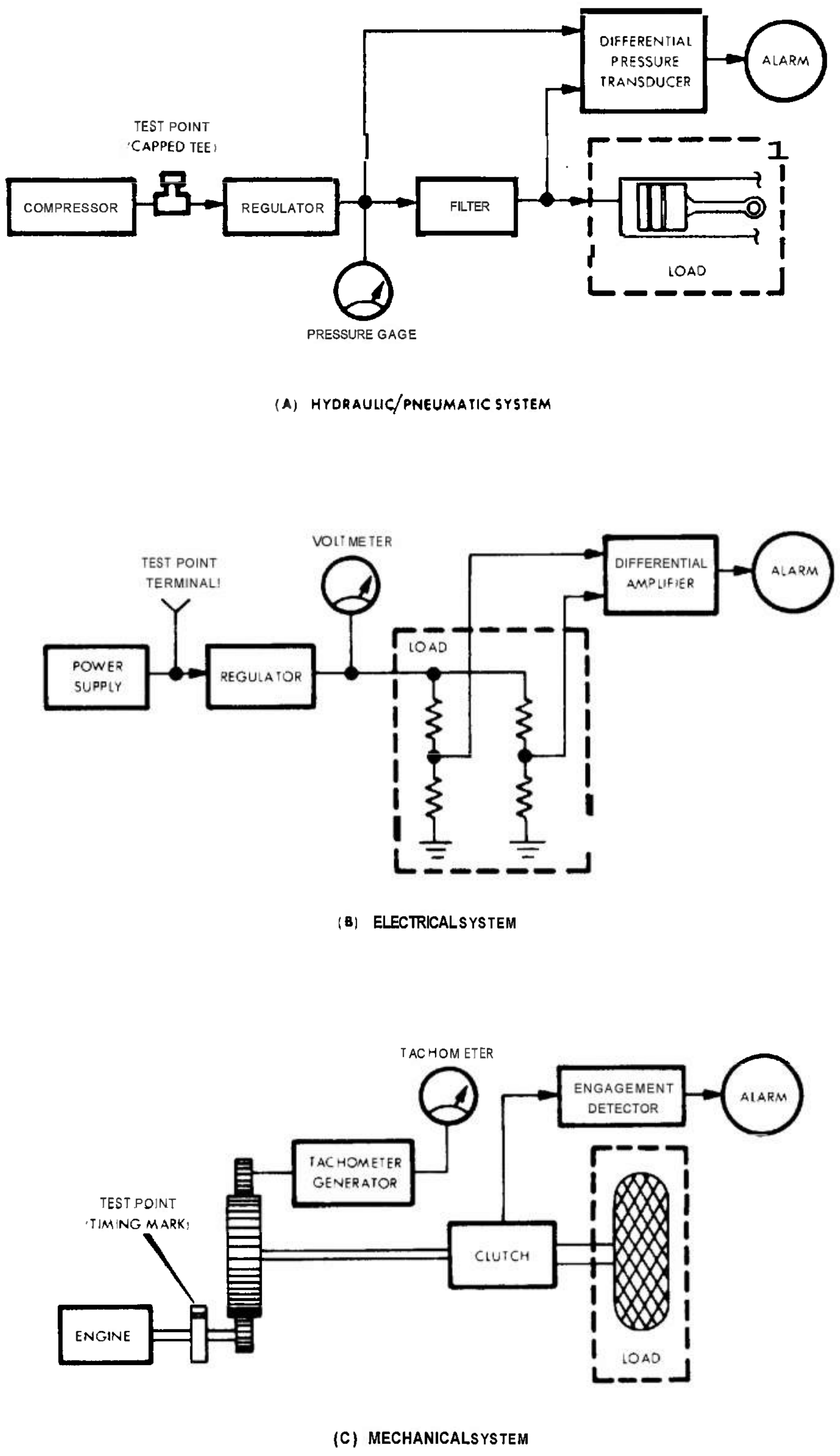


Figure 9-4. Built-in Troubleshooting Aids

device used to evaluate the operational condition of a system or equipment to identify and/or isolate any actual or potential malfunction. TMDE must give a measurement or indication of the operational condition of the system or unit under test (Ref. 5). Practically speaking, TMDE provides the man-machine interface enabling assessment of materiel performance parameters which the maintenance technician cannot directly see, hear, touch, or smell.

TMDE has a significant influence on the overall diagnosis and troubleshooting process. This influence is felt primarily in the form of time, and in the form of skill and training requirements. TMDE also has a significant influence on operational availability and maintenance and logistic requirements. These subjects are discussed in par. 9-2.5.3.

9-1.2.3.1 TMDE and Personnel Interface

As a general rule, diagnosis and troubleshooting are the most time consuming elements of corrective maintenance performed on electronic and electrical equipment. The time required, however, can be reduced by application of TMDE that confines the human involvement either in terms of thought processes or physical activity. For example, an electrical test console simultaneously may present dozens of status indications of system or equipment performance to the technician/operator. Localization and isolation of a malfunction based upon these indications may require the mental assessment of many display combinations, each having significance relative to malfunction location. This same test console, if so designed, could be made to eliminate the requirement for much of this thought process, but at a probable increase in cost and complexity.

Fig. 9-5 provides a simplified example of how TMDE can be designed to reduce human thought processes during diagnosis and troubleshooting. Each section of the figure shows equipment comprised of a series string of functions A through C. Function B is dependent upon function A, and function C is dependent upon function B. A malfunction appearing at the output of a function will "ripple" through the string, causing malfunctions to appear at the outputs of subsequent functions.

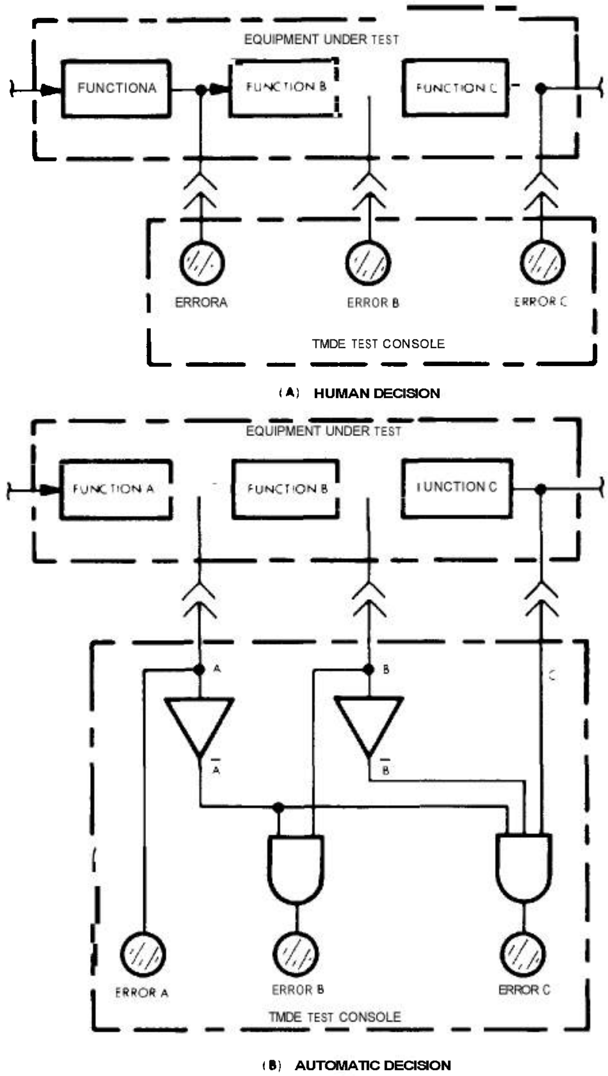


Figure 9-5. TMDE and Human Factors Interface

In Fig. 9-5 **(A),** the output of each function is monitored directly by an indicator on the TMDE test console. With this arrangement, an error at output function A will cause the ERROR A indicator to light, and, due to the ripple-through characteristic, also will cause ERROR B and ERROR C indicators to light. In this situation, the technician must follow a logical thought process and conclude that lighting of all error indicators actually means that function A has produced the error, and ERROR B and ERROR C indicators should be ignored. An error at the output of function B (output of function A being correct) results in the lighting of the ERROR B and ERROR C indicators, thus requiring yet a different diagnostic thought process.

Fig. 9-5 (B) depicts a TMDE design that performs the technician's thought process automatically. In this case, the actual error cause is the only one which produces a lighted indicator, regardless of the ripple-through characteristic of the series string. An error at the output of function A continues to produce errors at the outputs of functions B and C. The ERROR B indicator, however, is kept from lighting by the inverter and AND gate that precede it. To light ERROR B indicator, the gate that drives it must be supplied with errors from functions A and B. While both of these errors actually exist. in the equipment, the error from function A is inverted by the TMDE and becomes "error not A" ($\overline{A}$) at the gate input. Thus, lighting of the ERROR B indicator is precluded. Likewise, lighting of the ERROR C indicator is precluded except in those cases when only the output of function C is erroneous.

The design and/or selection of TMDE also influences the skill and knowledge levels required of the maintenance technician. As discussed in conjunction with the example in Fig. 9-5, TMDE can be made to perform selected portions of the malfunction analysis process automatically, thus reducing the amount of knowledge required of the technician.

Computer-based systems use the computer to accomplish automatic malfunction analysis of complex electronic materiel. The use of the computer to perform automatic fault isolation can minimize the skill level requirement of the maintenance technician and reduces required corrective maintenance time. The computer-based system normally encompasses features that include self-test, dynamic operational monitoring, automatic built-in fault isolation routines, automatic visual displays or instructions, and software routines for detailed diagnosis.

Typically, the computer-based system provides automatic fault isolation to a module, circuit board, or other replaceable part/assembly for a large percentage of the total failures. Dynamic monitoring of selected system functions during operational missions permits the computer to detect materiel malfunction immediately and to advance automatically into a pre-established fault isolation routine. The results of this routine may permit identification of a replaceable part/assembly, a group of replaceable items, or a major assembly. In the case of the latter, further isolation to a specific replaceable item normally is accomplished by the use of additional software routines. The identification of additional corrective action steps to be taken may be indicated by visual indicators such as alphanumeric displays or tape printouts. These indicators, combined with detailed instructions in technical manuals, provide the maintenance technician with the information he needs to perform the corrective maintenance action.

Since the computer-based system uses the computer to control both operational and fault isolation processes, it is of prime importance to insure satisfactory operation of the computer. This function normally is achieved through the use of built-in self-test features or through the use of these features in combination with detailed software routines.

Computer-controlled TMDE normally is not used to troubleshoot nonelectronic materiel. However, the complexity of such materiel is increasing, and the maintenance technician must be provided with increasingly sophisticated TMDE in order to maintain skill and diagnostic time requirements at acceptable levels.

While it is essential that TMDE selection be predicated upon the maintenance plan specifically tailored for a particular system or equipment, the maintenance engineer should make every attempt to identify and use existing TMDE to the maximum extent possible.

9-1.2.3.2 TMDE Index and Register

Within the major commodity commands, there are numerous existing items of general and specialized TMDE. Department of the Army Pamphlet 700-21, *The Amy Test Measurement and Diagnostic Equipment Register Index and Instructions,* contains a comprehensive listing of the TMDE available within the various commodity commands. Fig. 9-6 depicts the information flow to and content of the register index. The source document for information contained in the register is the TMDE item technical description. The index basically is divided into two sections: the register index and instructions, and the managing command index.

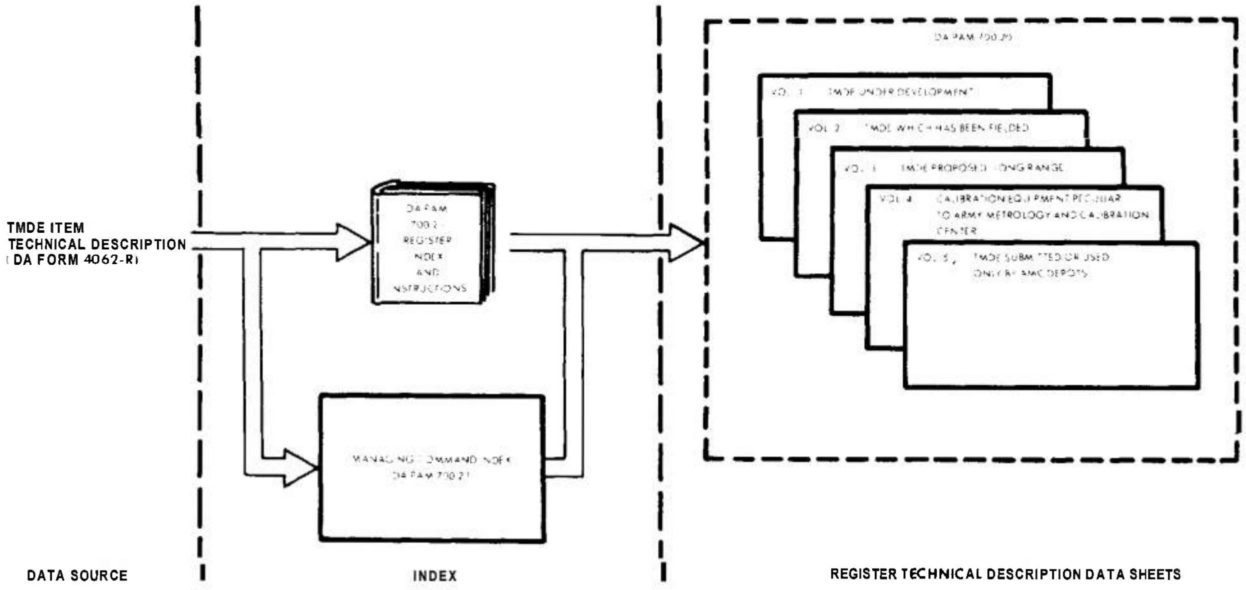


Figure 9-6. Flow and Conteni of TMDE Index and Register

The register index and instructions is a document that identifies the location of descriptive TMDE technical data contained in the register by nomenclature index, functional index, joint electronic type designation, system index, manufacturer's model number index, and material stock number index. The managing command index is on microfiche and identifies the TMDE by each AMC commodity command and selected DA agencies.

The register technical description data sheets (DA PAM 700-20) are contained on microfiche cards or microfilm and consist of the five volumes as shown in Fig. 9-6.

Secondary items such as panel meters, gages, and time totalizers are not considered significant TMDE for inclusion in the register; however, when items of this nature have unusual characteristics and/or appear applicable to broad Army application, entry into the TMDE register is not precluded. Common tools and measurement tools normally in General Services Administration (GSA) stock catalogs also are excluded from the register as TMDE.

9-1.2.4 Environment

The maintenance environment has a significant influence upon the diagnosis and troubleshooting process. This influence perhaps is felt most strongly at the lower maintenance levels (user and field) where maintenance services typically are brought to the malfunctioned materiel. Some Army materiel categories that most frequently are involved in such cases are aircraft, combat vehicles, construction equipment, and missile systems. All of these categories have certain characteristics in common, in that they tend to be fixed or relatively immobile, and particularly large and/or heavy. For the most part, they are "repaired where they fail", at least to the point where a malfunctioned component or assembly can be removed and returned to an established maintenance facility.

In-place diagnosis and troubleshooting may mean exposure to the full range of climatic conditions: high humidity, rain, wind, excessive heat or cold, and snow or ice. For this reason, it is extremely important that the maintenance technician be provided with an effective combination of system design, built-in troubleshooting aids, and TMDE. It is also important that the complexity of maintenance tasks be reduced to the lowest possible level.

The diagnosis and troubleshooting process in an adverse environment requires that system or equipment packaging be arranged in readily replaceable components or assemblies. To assist in diagnosing and troubleshooting to the replaceable item, such items should be functional in nature with a minimum number of interfaces with other system elements.

Built-in troubleshooting aids and features, as well as TMDE, should provide discrete, unambiguous, go/no-go indications of system or equipment status. Precise, quantitative measurements require exactness and concentration on the part of the maintenance technician, and are not compatible with an adverse environment.

Equally important to the functional packaging of materiel is the matter of providing adequate accessibility. Aircraft designs, which must exhibit high structural strength at minimum weight, normally have poor maintenance access characteristics. Environment/temperature control equipment, such as heating and air conditioning units, generally being an integral part of a building or equipment structure, also may present access difficulties.

Timely application of good maintenance engineering practices during design of a system can be of significant value in reducing overall troubleshooting and maintenance difficulty. Frequently, a design arrangement unfavorable to maintenance occurs because the designer is not aware of the optimum maintenance parameters for the planned operation and support.

In summary, certain types of systems and equipments inherently yield an unfavorable maintenance environment, or are operated and maintained in an unfavorable environment. The maintenance engineer can alleviate environment-related deficiencies by insuring that an accessible, functionally arranged mechanical and electrical packaging design is used, and that both TMDE and built-in troubleshooting aids and features are designed to provide for direct, unambiguous diagnosis and troubleshooting and subsequent repair.

9-1.3 DIAGNOSIS AND TROUBLESHOOTING CONSIDERATIONS BY ARMY COMMAND CATEGORY

The preceding paragraphs discuss the principles of diagnosis and troubleshooting and factors that influence their accomplishment. The paragraphs that follow describe how the principles and factors affect the diagnosis and troubleshooting accomplished during corrective maintenance of the major categories of Army materiel. These categories are:

a. Fixed plant/defense communications and United States Army Security Agency (USASA) equipment

b. Army aircraft

c. Automotive and mobile electrical power generating equipment

d. Combat vehicles

e. Construetion/materiel handling equipment

f. Small arms

g. Environment/temperature control equipment

h. Weapon systems

i. Missile systems

j. Munitions

k. Computer-based electronic systems

l. Tactical communication and electronic equipment.

9-1.3.1 Fixed Plant/Defense Communications and USASA Equipment

This equipment category includes radio, teletype, facsimile and similar types of terminal equipment, data transmission systems, and associated security devices. Heavy-duty radio transmitters and microwave elements within this category tend to be fixed equipment by virtue of their size, weight, and interfaces with power sources and antennas. While much of the equipment in this category is purely electronic in nature, items such as facsimile and teletype devices also incorporate mechanical and electromechanical components. Other items, such as large transmitters, which dissipate particularly high energy levels, may incorporate pneumatic or liquid cooling provisions. On-site maintenance of fixed plant/defense communications and USASA equipment thus varies considerably, depending upon the particular item involved. Relatively small items such as receivers, coders, and low capacity power supplies simply may be replaced with an operable repair part and returned to a maintenance shop for diagnosis, troubleshooting, and repair. For more recent equipment incorporating solid state components, diagnosis and troubleshooting typically are performed to the replaceable subassembly or module level. Defective subassemblies either may be returned subsequently to a depot for repair or discarded. Such a decision generally is based upon maintenance engineering analyses, which compare the economic and technical factors associated with each approach.

Diagnosis and troubleshooting of malfunctions occurring in large, fixed equipment generally are performed on a readily replaceable component or assembly initially, with the replaced item then being removed for further, more detailed repair in a shop facility. At times, however, diagnosis and troubleshooting must be performed to the most detailed part level. This is particularly true in those cases where malfunctions occur in internal equipment wiring harnesses, or where even the discrete piece part itself represents a large and bulky item. An example of this latter case might be a final output tube from a high-power radio transmitter.

Large, centralized communication offices or centers generally are equipped with both troubleshooting aids within the various individual equipments and centralized monitoring consoles or panels that relate the operational status of the overall installation. Abnormal indications reflected at the centralized monitoring facility generally can be relied upon to localize the source of a malfunction to a specific equipment or equipment grouping. Further localization and isolation to the replaceable item then are accomplished by use of a combination of troubleshooting aids built into the equipment and selected items of TMDE.

Such TMDE is of two basic kinds: standard and special purpose. Typical examples of standard TMDE are meters, oscilloscopes, and signal generators. Typical examples of special-purpose TMDE are telegraph test sets, printed circuit card testers, and envelope delay test sets.

The environment in which maintenance of fixed plant/defense communications and USASA equipment is performed generally is favorable, primarily because much of the equipment requires a temperature- and humidity-controlled operating environment. Of necessity, antenna arrays and their supporting structure frequently are exposed to the elements, although radomes and other devices are used when the equipment protection they afford is required.

Problems associated with diagnosis and troubleshooting of large-scale communication systems arise out of the vast quantity of interfaces involved, and the necessity for close coordination of all maintenance activities so that vital communication paths will not be disrupted.

9-1.3.2 Army Aircraft

Army aircraft are classified as either fixed-wing or rotary-wing. The fixed-wing aircraft are used for observation, transportation, and training purposes. The rotary-wing aircraft (helicopters) are used for attack and utility purposes in addition to those mentioned for fixed-wing aircraft.

Both aircraft classes are comprised of numerous and complex functional systems. The structural systems primarily are made up of the fuselage, tail boom, and alighting or landing gear. The mechanical drive system consists of power plant, drive shafts, transmission, rotors or propellers, and gearboxes. The hydraulic system in helicopters is a manual assist to the mechanical flight control system. In fixed-wing aircraft and large transport helicopters with landing wheels, a hydraulic system controls the brakes. Fuel control systems control the rate at which fuel is admitted to the respective engines. The electrical equipment includes batteries, generators, wiring, lights, and aircraft instruments. The utility equipment includes heating and air conditioning systems. The avionic system consists of instruments, and communication and navigation equipment.

Attack helicopters are equipped with armament that has a variety of mechanical, electrical, and hydraulic functions.

Diagnosis and troubleshooting activity begins with observations of instrument panel indicators and caution panel warning lights. It is augmented by observation of fluid leaks, blade strikes, hard landings, and unusual sounds. The use of spectrometric oil analysis to locate component wear is another step in the diagnosis and troubleshooting activity.

Many standard items of TMDE are now available for scientific support of aircraft maintenance (see the TMDE register). These standard items as well as special devices such as test stands for engines, fuel controls, servos, fuel systems, and ordnance launchers should be used when indicated by the technical manuals.

The Automatic Inspection, Diagnostic and Prognostic System (AIDAPS) is now being designed for the life cycle support of U.S. Army Aircraft. The AIDAPS techniques are aimed at the problems that cause the cost of maintaining Army aircraft to be so high. AIDAPS will monitor the indicators of mechanical and functional performance degradation with airborne equipment. The collection of vibration, pressure, and temperature data will be the basis from which trends toward component failure will be observed. The major aircraft components such as engine, transmission, gearboxes, and drive shafts will be removed and replaced only when their condition warrants it. Maintenance manhours will be lower. Expectations are that there will be fewer incorrect diagnoses and the requirements for replacement parts will be reduced.

Because of the size, weight, and handling characteristics of aircraft, most maintenance at the lower levels is performed at the aircraft in the existing natural environment. In addition to climatic extremes, the environment may include maintenance locations that are unimproved in terms of access roads, parking ramps, and other commonly expected features. This is true particularly during periods of active enemy engagement, when aircraft operate from forward area resupply points.

Problems associated with the diagnosis and troubleshooting of Army aircraft center about the poor access characteristics that most aircraft exhibit, and the necessity for insuring that aircraft flightworthiness and safety have not been compromised due to maintenance. Simply stated, malfunctions related to aircraft or crew safety must be diagnosed correctly and positively the first time.

9-1.3.3 Automotive and Mobile Electrical Power Generating Equipment

Automotive and mobile power generating equipment, like aircraft, represents a mix of functions. Involved are mechanical engines and drive trains, fuel systems, electrical systems, etc. Maintenance of this equipment, however, is understood more commonly than aircraft maintenance due to its performance at virtually every Army installation and its similarity to conventional commercial vehicle maintenance.

The TMDE used in the diagnosis and troubleshooting process is largely of a standard variety, although some specialized items are used. These include:

a. Speedometer testers

b. Engine exhaust analyzers

c. Fuel injection system testers

d. Steering alignment test stands

e. Generator, voltage regulator, and starter test stands

f. Specialized gages.

The environment in which diagnosis and troubleshooting are performed varies widely. Emergency repairs, or correction of vehicle-disabling malfunctions, often are made at the vehicle or generator set. Other malfunctions normally are diagnosed and repaired at established maintenance facilities.

Diagnosis and troubleshooting frequently are hampered by the necessity for dismantling large portions of the equipment before the condition of a suspected component or part can be assessed.

9-1.3.4 Combat Vehicles and Construction/Materiel Handling Equipment

A combat vehicle is defined as a land or amphibious vehicle, with or without armor or armament, designed to perform specific functions in combat. They may be wheeled or tracked vehicles, but in all cases are designed for high mobility in cross-country operation. Combat vehicle types include tanks, armored personnel carriers, self-propelled, tracked artillery, and other track-laying vehicles, whose primary purpose is delivery of firepower, supplies, and/or personnel (Ref. 6).

Construction equipment includes automotive vehicles, earth movers, cranes, batching plants, crushers, pavers, mixers, generators, compressors, pumps, drills, welders, forms, and other items of equipment (excluding hand tools) used or capable of being used in construction work (Ref. **1**).

Materiel handling equipment comprises items such as cranes, hoists, davits, dollies, and slings used for handling of end items. Equipment formally designated as material handling equipment also may be used to handle materiel. Included in this category are forklifts, platform lift trucks, warehouse cranes, straddle trucks, etc. Handling equipment is either mobile within itself, as in the case of a forklift, or mounted on a mobile platform, as in the case of a crane.

The combat vehicle and construe-tion/materiel handling equipment Army command categories are combined because of their similarity in nature: large, bulky, heavy, and mobile to a common degree (tracked or multi-wheeled) and not basically "road" vehicles in the sense of automobiles or conventional trucks.

This category of equipment has the characteristics of automotive and mobile electric power generating equipment (par. **9-1.3.3**) in addition to extensive hydraulic systems incorporated because of hardware bulk in the case of combat vehicles, and hardware function in the case of construction equipment.

The TMDE used in the diagnosis and troubleshooting process includes items related to the automotive and mobile electrical power generating equipment category (par. **9-1.3.3**). In addition, peculiar TMDE for this category includes:

a. Cross-drive transmission test systems

b. Multiple drive chassis dynamometers

c. Specialized optics testers (for armament items)

d. Barrel wear gages

e. Wheel and shaft balancers.

Repair of failures that immobilize this equipment normally is performed at the physical location of failure because the size, weight, and mobility characteristics of the equipment make on-site maintenance more desirable than returning to shop facilities. This is true especially in the case of tracked vehicles (tanks, armored personnel carriers, bulldozers, etc.) when failure of the tracks, rollers, idlers, or other components of the propulsion system would make retrieval difficult. As a result, the maintenance environment may vary widely from favorable to hostile.

The problems associated with diagnosis and troubleshooting are related to the size, bulk, and weight of the equipment and the maintenance environment, which, because of immobility of equipment, may be hostile.

9-1.3.5 Small Arms

Small arms are comprised of individual and crew served weapons through 0.60 caliber, as well as all types of grenade launchers. Because of the density of this equipment, maintenance personnel are able to maintain proficiency in the identification and rapid repair of malfunctions.

The majority of the diagnosis and troubleshooting of this equipment is through visual examination and by the performance of mechanical measurements for tolerance, wear, etc. Both organizational and field maintenance normally result in the replacement of worn, broken, or missing parts. In addition, the field maintenance level performs all required adjustments and those alignments that can be accomplished without heat treatment or special jigs.

The TMDE consists largely of measuring devices such as gages.

The maintenance environment in which diagnosis and troubleshooting are performed is reasonably favorable. Because of the size and weight of small arms, the organizational technician, at worst, will work in a tent or covered truck. Field level shelters will be as good or better. During combat, shelters at both levels are subject to hostile fire.

There are no particular diagnosis and troubleshooting problems associated with small arms. **The** causes of most problems that can be corrected at the lower maintenance levels can be identified readily because of the accessibility of virtually all operating parts to visual inspection.

9-1.3.6 Environment/Temperature Control Equipment

Environment/temperature control equipment includes air conditioning, dehumidification, heating, and refrigeration equipment. The equipment represents a combination of electrical, hydraulic/pneumatic, and mechanical functions or subsystems.

Maintenance of this equipment at the organizational level usually is limited to the replacement of defective materiel such as blower motors, compressors, condensers, valves, etc., which do not require special tools or equipment, breaking into the refrigerant circuit, complex or critical adjustments, or charging, flushing, or alignment after replacement. Field maintenance consists of the repair of ducting, hoses/piping, condensers, evaporators, coils/cores, and refrigerant leaks, and of the flushing and recharging of systems. Considerable preventive maintenance on this equipment is performed in the nature of cleaning and checking of operating fluid levels, pressures, etc. Typical specialized TMDE used in the diagnosis and troubleshooting process includes:

a. Cryogenic refrigerator test set

b. Relative humidity tester

c. Refrigerant service kit.

The environment in which diagnosis and troubleshooting are performed varies widely and will depend upon the category of equipment that is being protected by the environment/temperature control equipment.

Diagnosis and troubleshooting of this type of equipment are hampered by a lack of built-in aids and features (for example, a refrigeration system normally does not provide test points, and thus charged lines must be tapped or otherwise opened to verify operation of the refrigerant system). In addition, since these equipment types perform controlling functions, the influence due to the control/monitoring interface may present difficulty in the diagnosis and troubleshooting of alignment and calibration problems. For example, unsatisfactory temperatures in an air conditioned facility can result from inadequate equipment operation, or from improper planning regarding external temperatures, facility heat transfer coefficients, internal heat generated by personnel and materiel, efficiency of air distribution ducts, etc.

9-1.3.7 Weapon Systems, Missile Systems, and Munitions

A weapon system is a weapon and those components required for its operation. It is a composite of equipments, skills, and techniques that form an instrument of combat. The complete weapon system includes all related facilities, equipment, materiel, services, and personnel required for the support and operation of system elements so that the instrument of combat becomes a self-sufficient unit of striking power in its intended operational environment (Ref. 1).

Most Army weapon systems include several of the major Army materiel categories listed in par. **9-1.3.** Since a missile weapon system includes a missile system and munitions, it was decided to discuss the diagnosis and troubleshooting of weapon systems, missile systems, and munitions as an integrated function by using the currently deployed PERSHING 1a Field Artillery Missile System as a data source.

9-1.3.7.1 Maintenance Concept

The maintenance concept for a weapon system basically is the optimized integration of the individual maintenance concepts for each of the materiel items comprising the total system. The general philosophy for the maintenance concept of a weapon system emphasizes:

a. Elimination of or minimal requirements for disassembly of equipment by using units in the performance of authorized maintenance operations

b. Accomplishment of corrective maintenance below depot level primarily by the replacement of modules (components and assemblies) rather than piece parts; i.e., modular maintenance

c. Use by support maintenance units of highly mobile (to include air transport) contact teams to provide support to using units on-site when cost-effective and justified by operational requirements

d. Direct exchange by maintenance support units of designated modules and nonvehicular, mission-essential end items from serviceable stocks for unserviceable like items rather than repair and return of the same item to the supported unit

e. Use of maintenance float to provide immediate replacement of vehicular, mission-essential end items requiring or undergoing extended repair or scheduled depot maintenance.

The basic maintenance support structure (e.g., organizational, direct support, general support, and depot maintenance) must accommodate all types of support; however, it permits a variety of alternative approaches to the support of a specific item. In developing concepts for the maintenance support of specific commodities or weapon systems, consideration must be given to tailoring this basic support structure to the particular commodity or system. This assures the most effective and efficient use of maintenance resources in sustaining the required degree of operational availability of the item. Combining categories of the basic maintenance support structure, when cost-effective, may be used for this purpose. For example, all maintenance operations to be performed below the depot maintenance level may be allocated to the organizational maintenance category, or a single level of support maintenance (combined direct and general support) may be established between the organizational and depot maintenance categories (Ref. 7).

The maintenance concept for the PERSHING 1a missile system is presented in par. 4-3.2.1. The total weapon system consists of firing equipment, support equipment, and ancillary equipment. The diversification of types of equipment categories within a weapon system is illustrated in summary form in Table 9-1 for the PERSHING 1a missile system.

TABLE 9-1. WEAPON SYSTEM EQUIPMENT AND TYPE CATEGORIES (PERSHING 1a)

Major Items	Function	Type Categories or Classification
Firing Equipment:		
Programmer-Test Station (PTS)	Programs the trajectory of the missile, automatically controls the firing sequence, performs simulated airborne missile operation test, and provides the operator with visual indications of the firing sequence.	Digital computer, analog circuitry, air conditioning, heating, tape reader, printer
Erector-Launcher (EL)	Provides a base to hold and transport the missile during ground operation, a means to erect the missile for launch, and a level platform from which to fire the missile.	Mechanical, hydraulic, electrical, electro-mechanical

TABLE 9-1. WEAPON SYSTEM EQUIPMENT AND TYPE CATEGORIES (PERSHING 1a) (Cont'd)

Major Items	Function	Type Categories or Classification
Power Station (PS)	A skid-mounted, self-contained power source that produces AC and DC electric power, high-pressure air, and conditioned air.	Electrical power generating equipment (DC generators, AC generator), air conditioning, pneumatics, turbine engine, batteries, electrical, mechanical, electromechanical
Radio Terminal Set (RTS)	A self-contained, transportable shelter that provides both voice and teletype systems.	FM transmitters, FM receivers, teletypewriter, antenna, engine generator set, gasoline engine
Azimuth Laying Set (ALS)	Provides for alignment of the missile platform to the firing azimuth.	Tripods, theodolites, electrical controls, and lathe bed
Missile (1st stage, 2nd stage, guidance section, warhead section)	Performs propulsion and guidance functions, and transports warhead to target.	Airborne computer, stabilized platform, inverter, distributor, munitions, hydraulics, electronics, electrical, pneumatics
Equipment Carriers	Provide mobility for the major items: PTS/PS, EL, and RTS. Carriers consist of 5-ton 8 x 8 trucks and semitrailer vehicles.	Automotive
Support Equipment:		
Power Station, Trailer Mounted (PSE)	Provides the power source for rear area facilities.	45-kW generators, DC generators, air conditioning, air compressor
System Components Test Station (SCTS)	Used in performing rear area maintenance.	Same features as PTS; in addition, contains pneumatics and assembly test equipment
Field Maintenance Shops	Provide a mechanical and electrical repair capability.	Portable test equipment, mechanical tools, etc.
Ancillary Equipment:		
Wrecker, davit, lift trucks, hoisting beams, multiple-leg slings, shipping and storage containers, boarding ladders, winterization kits	Provides for efficient storing, handling, and loading of the system under varying transport and firing conditions; heating and insulation against weather are provided.	Handling equipment, mechanical, hydraulic, automotive, heating blankets, gasoline-fired heater, etc.

9-1.3.7.2 Diagnosis and Troubleshooting

The diagnosis and troubleshooting process of a weapon system is a function of the inherent design of the equipment items comprising the whole and of the system maintenance concept. Adherence to the following general design and procedure guidance will facilitate the accomplishment of weapon system diagnosis and troubleshooting:

a. Use go/no-go displays.

b. Incorporate an adequate number of accessible test points for either automatic or manual monitoring.

c. Provide automatic fault isolation when cost-effective and applicable to the materiel type.

d. Provide brief, simple, step-by-step procedures.

The foregoing guidance was followed in PERSHING support planning and is reflected in the paragraphs that follow.

Diagnosis and troubleshooting of the programmer-test station are accomplished automatically with its computer and programmed tapes. A computer diagnostic tape is used for fault isolating the computer, maintenance panel, tape reader, and countdown control panel. An adapter diagnostic tape is used for fault isolating the adapter and wiring harnesses going to the cable entry panels. Isolation by automatic means is to within one to five cards or modules for 85 percent of the failures. The card and module test set diagnostic tape is used for fault isolating components in the test set. Automatic troubleshooting is used also for isolating defective printed circuit cards and modules by use of the card and module test set, and one of two card and module programmed tapes. Display of the step number and reference to the technical manual enable the maintenance technician to perform the recommended corrective action. For the small percentage of cases not isolated automatically, manual procedures are provided.

Fault isolation of the erector-launcher is accomplished by the monitoring of go/no-go indications on the control panel and pressure gages on the hydraulic system in addition to the use of the human senses for observation of abnormalities in mechanical and hydraulic operations.

The ordnance (propulsion motor bottles, shaped charges, etc.) is handled under cognizance of the Armament Command. Generally speaking, the area of prime concern related to munitions is safety of personnel and materiel. Safety includes the consideration of handling during shipping and storage (i.e., the type of packaging, marking, etc.), ammunition storage (i.e., location, quantity-distance relationships, magazine storage, stability of munitions), and the special handling and procedures established in case of ammunition malfunction (i.e., area evacuation, special personnel, containerization, special facilities, and location).

Fault isolation of the power station is provided by monitoring its status panel and by the use of detailed step-by-step troubleshooting procedures (see Fig. 4-5).

Automatic fault isolation to the missile section level is accomplished by monitoring the operational status of the missile with the programmer-test station.

The system components test station (SCTS) is used to perform rear area maintenance. As a housed mobile center, the SCTS uses a computer and tape programs for testing missile sections, together with assemblies, cards, relays, and modules from the guided missile and associated ground support equipment. Diagnostic tape programs also are provided for verification and troubleshooting of major SCTS assemblies. The SCTS contains a dismounted programmer-test station and has facilities whereby one missile guidance section can be tested and another repaired simultaneously under controlled temperature conditons.

Both organizational and field technical manuals for the PERSHING system contain functional description data presented as functional description diagrams, power distribution diagrams, block diagrams, and schematics. Descriptive text is integrated within the diagram itself. Fault isolation data are presented as troubleshooting diagrams and tables and are used in conjunction with the functional description data to locate malfunctions from an overall system level, through the assembly and chassis level, to a card, relay, or component level. The presentation of fault isolation and functional description used is an adaption of the Symbolic Integrated Maintenance Manuals (SIMM's) method of presentation. The maintenance technician uses the functional description and fault isolation data presented in this manual for the following:

a. Familiarization with the functional aspects of the equipment

b. Troubleshooting the equipment at a system level

c. Analyzing self-test and diagnostic programs.

In addition, rear area technical manuals contain diagnosis and troubleshooting procedures for assemblies and chassis of the SCTS, programmer-test station (PTS), erector-launcher (EL), and the missile that can be fault isolated as units under test (UUT's), using automatic troubleshooting test equipment contained in the SCTS van. Each maintenance data package contains a UUT program, an exploded view of the UUT being tested, and a schematic of the UUT. The technical manuals also contain procedures for checking printed circuit cards, modules, and relays contained in the SCTS, EL, PTS, and missile. The test equipment contained in the SCTS van accomplishes this checkout by means of programmed tapes. In addition, the manuals contain procedures for checking a missile first stage in container, a missile second stage in container, a missile guidance section in container, a guidance section on test dolly, missile sections (less warhead section) in containers, various tests of the guidance section inertial platform air supply system, and procedures for testing the azimuth laying control box. The maintenance technician uses each of the procedures contained in the manual to accomplish a complete checkout of the missile system.

The maintenance environment of the PERSHING missile system varies from the all-weather conditions encountered at the firing site to the in-van, environmentally controlled conditions at the support unit. Basically, the environments encountered for the materiel items are the same as those previously discussed for the equipment categories that comprise the system. The requirement for detailed maintenance in adverse environments is circumvented to some extent by the use of float items and replacement of missile sections at the firing site.

Diagnosis and troubleshooting problems are minimized by the extensive use of automated techniques. Malfunctions that do require manual troubleshooting generate the problems typical of the involved equipment category.

9-1.3.8 Computer-based Electronic Systems

Computer-based electronic systems are those electronic systems that have a computer as an inherent part of the prime equipment. In its operational role, the computer monitors, operates, and controls itself and the remaining prime materiel. Normally, the computer also is used to perform diagnosis and troubleshooting. In this role, it functions as described in par. **9-1.2.3.1.**

Maintenance normally is accomplished at the organizational and direct support levels by the replacement of knobs, fuses, indicator lights, and other simple components, modules, printed circuit cards, etc. Module and card repair is accomplished at the general support level and/or depot level.

The computer normally serves as the prime TMDE at the organizational and direct support levels. Specialized TMDE is used to repair cards, modules, etc.

The diagnosis and troubleshooting environment normally is favorable, since the equipment frequently is installed in temperature- and humidity-controlled environments.

Diagnosis and troubleshooting problems virtually are nonexistent when the computer is operating properly. Diagnosis and troubleshooting of a failed computer that cannot localize and/or isolate the fault require, at a minimum, general-purpose electronic TMDE, wiring diagrams, maintenance procedures, and highly skilled personnel.

9-1.3.9 Tactical Communication and Electronic Equipment

In addition to tactical communication equipment, this materiel category includes missiles, fire control and fire distribution equipment, avionic and optical systems, communication security (COMSEC) materiel, etc. Discussion will be limited to tactical communication, optical, and COMSEC equipment since the other equipment types, or similar types, are discussed in the preceding paragraphs.

Preventive maintenance consists of inspection, test, cleaning, minor adjustments, etc. With the exception of COMSEC materiel, organizational corrective maintenance consists of the replacement of modules that are easy to remove and replace, repair of cable assemblies, cable connectors, etc., and the replacement of components such as knobs, lamps, and fuses. For COMSEC materiel, organizational corrective maintenance normally involves the removal and replacement of end items, and of components similar to those previously identified.

Direct support maintenance accomplishes limited piece part repair on all except COMSEC materiel, the repair of which normally is limited to the exchange of plug-in modules. General support maintenance accomplishes piece part repair on all of the materiel types. Avionic materiel (less COMSEC materiel) receives all support maintenance at a single aviation intermediate support maintenance level.

There are no significant environmental problems associated with the diagnosing and troubleshooting of these materiel types. Equipment that is not installed and/or used in a protected environment is designed to permit evacuation of the complete item, or of easily removed, replaced, and transported modules, to a protected environment.

Except for faults, such as burned out lamps and fuses, and broken wires and connectors, that are obvious visually, diagnosis and troubleshooting are accomplished with a wide range of both special- and general-purpose TMDE.

One type of built-in TMDE which is seeing increasing application involves the use of integrated circuits and light-emitting diodes (LED). For example, one or more integrated circuits are designed to monitor the output of a complete module, such as a printed circuit card, and to illuminate a LED when the output is faulty. The integrated circuits are mounted on the card. The LED can be mounted on the card, or several can be grouped on a display panel. The organizational level diagnosis and troubleshooting processes are accomplished by observing that a LED is illuminated and identifying its associated card. Fault correction is accomplished by replacing the card. Depending upon the maintenance concept, the card is evacuated to a higher maintenance level for fault verification and repair or discard.

9-2 FACTORS RELATED TO DIAGNOSIS AND TROUBLESHOOTING (Ref. 7)

Human engineering includes the determination of man's capabilities and limitations as they relate to the operation, maintenance, and control of systems, and the application of this knowledge to the planning, design, and testing of each system to insure efficient, reliable, and safe human performance. Human factors is a more comprehensive term and is defined as a body of scientific facts about human characteristics. The term covers all biomedical and psychological considerations, including human engineering, life support, personnel selection and training, training equipment, job performance aids, and performance measurement and evaluation (Ref. 1).

The human engineer studies the human being as a user of equipment, and the equipment as a tool for a task. In liaison with hardware engineers and designers, human engineers seek to develop new and improved man-equipment interfaces that will simplify the operator's task and increase the probability of mission accomplishment.

Diagnostic and fault isolation techniques for equipment vary from manual (measurements of voltage, waveforms, fluid level, pressure, etc.) to automatic checkout techniques, alarm systems, and go/no-go indicators as fault locators.

In the overall diagnosis and troubleshooting action for items within the Army command categories, there are several particular areas related to the biomedical and psychological considerations that relate to man in a system: These areas are:

a. Control and display integration

b. Visual displays

c. Auditory displays

d. Controls

e. Labeling

f. Environment

g. Accessibility.

Visual displays provide the operator with a clear indication of the equipment or system condition. The operator must understand the presented information and, with minimum effort and delay, convert it into correct decision and/or control actions. Frequently, the displays are affected by the locations and operating methods of associated controls. These displays and controls should be designed and located so that the operator, with little or no training, will select the correct control and operate it in a manner designated by the display. Auditory alarm signals should be used to complement visual displays when extreme caution is mandatory, system or personnel safety is endangered, and immediate action is required.

Proper labeling should be provided at test points, supplemented by detailed troubleshooting diagrams, to aid in the step-by-step manual troubleshooting process. Proper identification of items, test points, and other areas prevents the conduct of inadvertent maintenance actions.

Man functions as a data-sensing device, receiving information through extremely complicated sensory mechanics. Each human sense organ has upper and lower sensitivity limits that define the range of energies to which the organ normally responds, producing the sensations of sight, hearing, taste, smell, and touch. Wide individual differences in data-sensing abilities exist which may be attributed to age, intelligence, specific innate capacities, physiological condition, and amount of training. The effectiveness of maintenance, which includes diagnosis and troubleshooting, is determined by the extent to which prime equipment, test equipment, and work environments fall within the capabilities and limitations of the available skills. These capabilities and limitations are of two principal kinds: physical limitations and maintenance skills. People vary in size, and therefore there are certain minimum and maximum dimensions of workspace and equipment that must not be exceeded if a man is to work at all. People are limited in the amounts of force they can exert and in the weight they can lift and carry. These limits, in turn, determine the access to equipment, the weights of test equipment and replaceable units, and the location for maintenance. The maintenance skill level of personnel, assuming that the inherent design has flexibility in maintenance, dictates the degree and level of diagnosis and troubleshooting in addition to the repair action. Normally, the least skilled individuals from the maintenance point of view are those associated with the operation of equipment.

9-2.1 HUMAN FACTORS AND TRAINING

In the training of personnel to perform diagnosis and troubleshooting, the basic human factors that should be considered are:

a. Displays. These include both visual displays and auditory signals and relate to information displayed, location and arrangement, coding, and signal type (tones, complex sounds, and speech).

b. Controls. These include arrangement and grouping, coding, and types of controls.

c. *Anthropometry.* This includes consideration of the nature, frequency, and difficulty of the related tasks, the position of the body during performance of these tasks, mobility or flexibility requirements imposed by the tasks, increments in the design-critical dimensions imposed by the need to compensate for obstacles, projections, etc., and increments in the design-critical dimensions imposed by protective garments, packages, lines, padding, etc. (Ref. 7).

d. Hazards and Safety. These include safety labels and general workspace hazards, equipment-related hazards, and electrical, mechanical, and toxic hazards.

The basic human factors are related to the inherent design of the materiel. At the time training begins, the system will have been designed and, through the guiding or influencing efforts of the maintenance engineering analysis process, the features that enhance supportability, maintainability, and human factors will have been considered and/or incorporated. The training in relation to troubleshooting, as affected by the inherent design, can only demonstrate effective use of the human engineering design (e.g., displays, controls, anthropometry) and stress any unusual anthropometry requirements, hazards, and safety precautions encountered during the diagnosis and troubleshooting process.

The complexity of military systems has resulted in tremendous increases in maintenance demands. In order to meet these increased demands, the services have been increasing both maintenance specialization and depth of training. These are required to equip technicians to accomplish reliable and timely maintenance that results in the satisfaction of operational availability requirements (Ref. 8).

Troubleshooting complexity and capability are the two major variables that affect troubleshooting time. Two major contributors to the time problem are the complexity of the required troubleshooting tasks and the reliability of the equipment. Complex troubleshooting tasks normally are time consuming and require highly skilled personnel, while reliable equipment prevents the technician from gaining sufficient on-the-job experience to retain the knowledge learned during the training program. The solutions to these problems are to design equipment to make the troubleshooting tasks less difficult and to provide a means for retaining an adequate proficiency level.

Equipment troubleshooting complexity can be reduced by designed-in maintenance aids. These aids range from simple test points to complex, fully automated diagnostic aids. An adequate troubleshooting proficiency level can be retained in two basic ways. First, the potential problem can be eliminated or alleviated by using automatic troubleshooting equipment. Personnel can operate such equipment effectively by following very elementary procedures. The second way is to provide procedures that are so complete and clear that they could be followed by a person with virtually no training.

9-2.2 MOS LEVELS

Military occupational specialty (MOS) is a term used to identify a grouping of duty positions having such close occupational or functional relationship that an optimal degree of interchangeability among persons so classified exists at any given level of skill. The military occupational specialty code is a fixed number that indicates a given military occupation specialty (Ref. 9).

The basic pattern of military personnel in acquiring the MOS begins with the basic combat training course, which is designed to provide the basic skills and knowledge to fight and survive in the field. Upon graduation from basic combat training, personnel may take one of four training routes. These are:

a. Assignment to a table of organization and equipment unit for on-the-job training (OJT) to qualify in an MOS or to use skills that were obtained in civilian life prior to Army entry.

b. Assignment to a training center to participate in advanced individual training to qualify in a specific infantry, artillery, ordnance, quartermaster, signal, transportation, etc., MOS.

c. Assignment to a training center that conducts combat support training to qualify in specialties such as clerk, clerk typist, supply clerk, cook, wheeled vehicle mechanic, light truck driver, etc.

d. Assignment to a service school to qualify in an MOS requiring more advanced technical training. Assignment to a service school can occur directly after basic combat training, after a period of on-job-training with a unit, or after advanced training at an Army training center (Ref. 10).

The MOS code consists of a combination of five alphanumeric characters as shown in Table **9-2.** The elements are defined as follows:

a. Occupational area is the term used to identify the major divisions of the MOS structure and permit logical grouping of career groups having an occupational or functional familiarity (see Table **9-3).**

TABLE 9-2. ELEMENTS OF MOS CODE (Ref. 11)

Elements	1st character (numeric)	2nd character (numeric)	3rd character (alpha)	4th character (numeric)	5th character (alpha)
Occupational area	Initial classification				
Career group	Career group identification				
MOS	Specialty identification				
Skill level	Identification of levels of specialization and leadership				
Special qualification,	Identification of parachutists, special forces, instructors, linguists, etc.				

TABLE 9-3. ENLISTED MOS CLASSIFICATION STRUCTURE (OCCUPATIONAL AREAS AND CAREER GROUPS) (Ref. 11)

1. Tactical Operations
   - 11 Infantry-Armor
   - 12 Combat Engineering
   - 13 Field Cannon and Rocket Artillery
   - 15 Field Artillery Missiles
   - 16 Air Defense Missiles
   - 17 Combat Surveillance and Target Acquisition
2. Missile and Fire Control Electronic Maintenance
   - 21 Ballistic Missile Electronic Maintenance
   - 22 Guided Missile Electronic Maintenance
   - 23 Missile Fire Control Electronic Maintenance
   - 24 Air Defense Missile Electronic Maintenance
   - 25 Fire Distribution System Repair
   - 26 Radar and Microwave Maintenance
   - 27 Combat Missile Electronic Maintenance
3. General Electronic Maintenance
   - 31 Field Communication Equipment Maintenance
   - 32 Fixed Plant Communication Equipment Maintenance
   - 33 Intercept Equipment Maintenance
   - 34 Data Processing Equipment Maintenance
   - 35 Electrical/Electronic Device Maintenance
   - 36 Wire Maintenance

TABLE 9-3. ENLISTED MOS CLASSIFICATION STRUCTURE
(OCCUPATIONAL AREAS AND CAREER GROUPS) (Ref. 11) (Cont'd)

4. Precision Maintenance
   - 41 Precision Devices
   - 42 Prosthetic Appliances
   - 43 Textile and Leather Repair
   - 44 Metal Working
   - 45 Armament Maintenance
   - 46 Missile Mechanical Maintenance
5. Auxiliary Services
   - 51 Construction and Utilities
   - 52 Power Production and Distribution
   - 53 Industrial Gas Production
   - 54 Chemical
   - 55 Ammunition
   - 57 General Duty
6. Motors
   - 61 Marine Operations
   - 62 Engineer Heavy Equipment Operation and Maintenance
   - 63 Mechanical Maintenance
   - 64 Motor Transport
   - 65 Railway Maintenance and Operations
   - 67 Aircraft Maintenance
   - 68 Aircraft Component Repair
7. Clerical
   - 71 Administration
   - 72 Communication Center Operations
   - 73 Finance
   - 74 Data Processing
   - 76 Supply
8. Graphics
   - 81 Drafting and Cartography
   - 82 Surveying
   - 83 Printing
   - 84 Pictorial
9. General Technical
   - 91 Medical Care and Treatment
   - 92 Laboratory Procedures
   - 93 Technical Equipment Operation
   - 94 Food Service
   - 95 Law Enforcement
   - 96 General Intelligence
   - 97 Special Intelligence
   - 98 Signal Intelligence

TABLE 9-3. ENLISTED MOS CLASSIFICATION STRUCTURE (OCCUPATIONAL AREAS AND CAREER GROUPS) (Ref. 11) (Cont'd)

0	Special Assignment	
	00	Special Assignment (NEC)
	01	Special Requirements
	02	Bandsman
	03	Special Services
	04	Linguists
	05	Radio Code
	09	Reporting Codes

b. Career group is the term used to identify a grouping of technically related military occupational specialties having similar mental, physical, and psychological requirements (see Table 9-3).

c. MOS is the alpha character which, in combination with the first two characters, identifies the specific military occupational specialty without regard to level of skill. For example, within group 21, ballistic missile electronic maintenance, "G" designates a PERSHING electronic materiel specialist.

d. Skill level is one of five levels as defined in Table 9-4.

e. Special qualification identifies special qualifications which are common to a number of specialties. This character is *0* when no special qualification is required or when the individual is not qualified for the award.

The levels of skill increase in relation to the military organizational levels (organizational, direct and general support, and depot maintenance). Progression from the organizational level to the depot maintenance level results in variance in the maintenance being performed from inspections, cleaning, servicing, preserving, adjusting, simple repair, and remove/replace actions to the repair of assemblies and detailed overhaul types of operations. Each of these tasks requires higher skill levels, and the skill requirements at these levels of maintenance are identified through the overall maintenance engineering analysis process.

Advancing technology, coupled with increased performance requirements for Army materiel, results in systems of ever-increasing complexity. Sophisticated test equipment is required to monitor the operational status of those systems and to perform diagnosis and troubleshooting. High skill levels are required to maintain the prime and support equipment. Such levels are in short supply.

Automatic fault isolation techniques may be advantageous both in providing the test capability and in the added function of reducing the number of maintenance personnel and the maintenance skill levels required to maintain the system. Such equipment automatically controls test sequences, compares responses with predetermined standards, and displays results. Consequently, qualitative and quantitative personnel requirements are reduced. However, indiscriminate use or selection of automatic test equipment should be avoided, since it may be costly and induce additional support requirements.

Qualitative and quantitative personnel requirements must be reduced on a systematic basis. Although gross estimates of personnel requirements may be the product of feasibility studies conducted in the conceptual phase, the detailed qualitative and quantitative personnel requirements are developed during full-scale development. In order to influence and control the impact of the design on the final personnel and skill requirements, development specifications should reflect such factors as:

a. Reduced requirements for field checkout personnel

b. Reduced operator training requirements

c. Reduced time requirements for checkout

TABLE 9-4. MOS SKILL LEVELS

Skill Level*	Definition
1	Identifies apprentice jobs involving simple tasks performed under general supervision or more difficult tasks requiring close supervision.
2	Identifies journeyman jobs involving difficult tasks that require general supervision.
3	Identifies advanced journeyman jobs involving tasks that are significantly different from and in addition to the tasks performed at the journeyman level, and requiring minimum supervision.
4	Identifies leader jobs involving relatively detailed knowledge of the tasks performed at all subordinate apprentice and journeyman levels in order to coordinate and give direction to the work performed.
5	Identifies supervisor jobs involving a broad, general knowledge of the tasks performed at all subordinate levels in order to coordinate and give direction to work activities.

*When two or more skill levels are authorized for use with an MOS, they are cumulative to include all lower skill levels, except skill level 4 (leader), which may not necessarily be cumulative to include skill level 3 (advanced journeyman).

d. Elim nation of operator skill as a critical factor

e. Elim nation of emotional stress as a factor

f. Elim nation of time pressures

g. High accuracy in reading and decision making

h. Better application of marginal testing techniques

i. Automatic isolation of malfunctioned components

j. Automatic programming and control of checkout and countdown sequence.

9-2.3 ADVANTAGES AND DISADVANTAGES OF TEST AND DIAGNOSTIC EQUIPMENT

In the overall maintenance task analysis process, the maintenance engineer must identify the need for test, measurement, and diagnostic equipment (TMDE). The diagnosis and troubleshooting procedure requires three primary sources of data: operational indicators, human senses, and outputs from TMDE permanently or temporarily connected to the system for the purpose of malfunction detection.

The functional complexity of a system is a factor that dictates the diagnostic complexity of the equipment. For systems such as mechanical or hydraulic systems, the human senses (sight, hearing, and touch) provide the primary elements of diagnostic data. In the case of complex electronic equipment, diagnosis of a malfunctioned item within the subsystem is limited if the diagnosis is based only on the knowledge gained from operational indicators and the human senses. As a result, in the case of complex electronics, in order to achieve a high degree of testability and to facilitate the detection and isolation to the replaceable unit, automatic testing is used. Due to the functional complexity of electronic equipment, it is impossible, or at least impractical, for the technician to troubleshoot the equipment manually. Consequently, a combination of hardware and software is used to assist the technician in troubleshooting with a minimum amount of personal participation or decisions.

After a decision is made that test, measurement, and diagnostic equipment is required, a second decision must be made as to the optimum equipment type. Maintenance engineering conducts design/support trade-offs to serve as a basis for the second decision. The optimum test, measurement, and diagnostic equipment will provide a mean time to repair that satisfies operational availability requirements at lowest life cycle cost.

9-2.3.1 Categories and Types

Test equipment falls under two categories and four general types. The categories are special purpose and general purpose; the types are built-in, automatic/semiautomatic, goho-go, and collating. These categories and types are not mutually exclusive, as a given test unit may incorporate some or all of the features of several of them in combination. Table 9-5 is a summary of the major considerations in the selection of test equipment. In reference to Table 9-5, the following definitions are applicable:

a. Special purpose is a category of test equipment which usually is designed for a specific system and is used to monitor or test a unique function of that system.

b. General purpose is a category of test equipment which normally is considered an "off-the-shelf" item (available in Government or commercial inventory) and which may be used in different systems.

c. Built-in test equipment is a type that is packaged mechanically and/or electrically with the prime equipment into end items. Components, modules, etc., within the end items may perform both prime and test equipment functions (computer-based systems), or different components, modules, etc., may be used in the accomplishment of the operational and test functions. Additionally, this type of test equipment may be connected continuously to the prime equipment by wires, etc., or may be connected manually on an as-required basis.

d. Automatic/semiautomatic test equipment is a type that normally checks two or more signals in sequence with no, or minimum, human interface. The test equipment may be built-in or separate. The first part of par. 9-**1.2.3.1** contains a typical example of automatic, built-in test equipment that functions without a computer. The last part of par. **9-1.2.3.1** describes the typical accomplishment of automatic fault isolation in a computer-based system. Depot Installed Maintenance Automatic Test Equipment (DIMATE) is an example of separate, computer-controlled test equipment.

e. Go/no-go test equipment is a type which may be one or a combination of the built-in and automatic/semiautomatic test equipment, and is designed primarily to determine if a system is within tolerance, but not to determine the relative degree of compliance.

TABLE 9-5. TEST, MEASUREMENT, AND DIAGNOSTIC EQUIPMENT CONSIDERATIONS

Categories of Test Equipment	Types of Test Equipment	Functional Tests	Types of Test Indications
Special-purpose	Built-in	System	Go/no-go
General-purpose	Automatic/semiautomatic	Item	Quantitative
	Go/no-go	Open loop	Marginal
	Collating	Closed loop	
	Computer software (prime equipment)	Static	
		Dynamic	
		Marginal	

f. Collating test equipment is a type which may be one or a combination of the built-in and automatic/semiautomatic test equipment, and is designed to present the results of two or more checks as a single display.

. The test equipment may be used to perform the test function, whether in the operational or the maintenance posture. Thus it is evident that the total system concept must be considered in relation to the identification of TMDE. The types of functional test that may be conducted on the system either in the operational or maintenance posture include one or a combination of the following types of tests: system, item, open loop, closed loop, static, dynamic, and marginal. These tests basically are self-explanatory by their nomenclature; however, for clarification, a marginal test is defined as a procedure for system checking which indicates when some portion of the system has deteriorated to the point where there is a high probability of system failure during the next operating period (Ref. 12). Marginal testing may yield one type of test indications or combinations of goho-go, quantitative, or marginal test indications, and usually involves the application of external stimuli under controlled conditions.

Materiel in an operational state normally is monitored for satisfactory performance. In most cases, this is achieved by automatic monitoring equipment that basically provides an indication of the presence or absence of key performance parameters. In the case of automotive equipment, these indications would be oil pressure, amperage, fuel level, and temperature. The advantage of the automatic monitoring equipment is that it relieves the human from making detailed tests or observations to determine equipment performance. In some cases, such as when equipment is automatically shut down, on the basis of the malfunction indication, the human is removed from the decision block. The type and complexity of the prime equipment and the magnitude of tests that must be made to determine operational performance are the basic factors that determine the advantage or disadvantage of automatic monitoring equipment. It provides efficient, quick, and automatic indications of performance, but may be costly, complex, and/or contribute to materiel failures; the overall effectiveness is determined by analysis through the trade-off process.

Equipments may have separate displays for operation and maintenance, especially when maintenance is to be performed while the equipment is operating. A built-in test panel generally provides a central location from which to monitor, control, check, and perform the materiel tests. The test panel normally contains test points, selection switches, and appropriate meters, scopes, and other measurement devices. Provisions for a built-in test panel must be considered during the design phase to insure that materiel test points are provided and located for convenient connection to the test panel. The built-in test panel may provide, by means of the test points (functionally grouped and labeled with a symbol or title), the interface by which external test equipment may be used. The built-in test panel, because of its central location, provides for efficient maintenance and troubleshooting and separates, to some extent, the operational and maintenance functions. The total test function includes the monitoring of both the operational and test indicators, but in some cases, the test function may be performed during the operation of the equipment on a noninterfering basis. The effectiveness of a built-in test panel is based on the availability and adequacy of test points, and the adequacy of the checking or troubleshooting procedures.

The maintenance engineer should evaluate each feature of the TMDE in terms of the demands that will be placed on the equipment and on the maintenance technician in the field as well as its impact on mean time to repair. Complex test equipment may simplify the job of the technician and reduce preparation time or turnaround time for complex systems; however, it may cause an increase in the maintenance total time because of its own maintenance burden.

9-2.3.2 Advantages and Disadvantages

Table 9-6 delineates the general advantages and disadvantages of each of the categories and types of test equipment. Although in specific cases of materiel the advantages and disadvantages delineated may not be applicable,

TABLE 9-6. ADVANTAGES AND DISADVANTAGES OF TEST EQUIPMENT (Ref. 14)

Test Equipment	Advantages	Disadvantages
Category:		
Special-purpose	Accurate, simple for task, meets special need of materiel	High cost, short life, high risk, field impact, scheduling problems for availability, unique materiel
General-purpose	Inexpensive, readily available, long life, supportable, user familiarity, user confidence, versatility	Requires ingenuity for adaptability, time consuming in maintenance process
Types:		
Built-in	Minimizes external support equipment, availability, minimizes downtime due to transport, no probing or manual connections in fault isolation, configuration status current with equipment, readily identifies performance degradation, no special transport or storage requirements	Prime equipment heavier, larger, more power demands, complex, higher cost, increase in maintenance, calibration integral to prime equipment and difficult due to inseparability, self-checking for test feature to insure performance required, inflexibility in test procedures, may be expended (e.g., missile system)
Automatic/semiautomatic	Rapid, increases test capability, controlled testing and consistency in test, eliminates human errors, reduces skill level and training for basic prime equipment task	Large, heavy, expensive, highly specialized, requires self-checking features, test point consideration in design for applicability, sensitive to design changes, complex, less reliable than manual, increases skill and training required for maintenance of test unit
Go/no-go	Simplifies decisions and maintenance tasks, information clear, concise, and decisive	Unique design circuitry, test unit costs high, scheduling problems, nonversatility for detailed circuit analysis.
Collating	Reduces number of indicators, checking time, and error, simplifies troubleshooting	Similar to goho-go and automatic, does not pinpoint specific signal malfunction.

the maintenance engineer in consideration of the TMDE application would determine, through the process of analysis, the degree of applicability of these items. The comparative size of the listings within the tables is not an indication of the relative merit of one category or type of test equipment compared with the other. As addressed previously, these categories and types are not mutually exclusive.

9-2.3.3 Design Principles

When analyzing for TMDE selection or design, the maintenance engineer should consider the following general criteria (Ref. 13):

a. TMDE will be compatible with the modular maintenance concept. TMDE design, selection, acquisition, and allocation must support this concept to the extent feasible, as determined by technological, economic, and operational considerations.

b. Easy-to-use and interpret go/no-go built-in test equipment will be incorporated in the designs of all Army materiel (tank/automotive, aviation/avionics, missiles, and communications/electronics) whenever technically and economically feasible.

c. Multipurpose TMDE will be developed for families of equipment for use at organizational levels of maintenance whenever the use of built-in test equipment is not feasible. Prime considerations will be given to go/no-go testing and ease-of-use and interpretation characteristics.

d. Multipurpose automatic TMDE capable of fault identification/isolation, diagnosis, and failure prediction will be developed and procured for use at all levels of maintenance consistent with cost and efficiency considerations and on the basis of level of replacement/repair authorized in the maintenance allocation chart.

e. TMDE designs will provide for standard, foolproof quick-connect/disconnect capability of the TMDE to or from the end item or system under test without, when practical, the need for manual insertion of sensors/transducers into the unit under test.

f. TMDE configurations will be determined through economic analysis, consideration of force structure, qualitative and quantitative personnel and training requirements, related support equipment requirements, and mean time to repair requirements.

g. Value, human factors, and system safety engineering principles will be considered in all TMDE configurations.

h. Sophisticated TMDE (i.e., TMDE capable of comprehensive fault identification/isolation/diagnosis and requiring application/interpretation/analysis by high technical skill levels) will be concentrated at the highest level of maintenance considered most productive and cost-effective.

9-2.4 DIAGNOSTIC HIERARCHY (Ref. 14)

The maintenance engineer, when analyzing the diagnostic and troubleshooting techniques, must consider the range of test approaches that are available for a specific equipment or system. The test approach must be compatible with the selected maintenance concept. Due to the interaction, any decision regarding either the maintenance concept or the test approach limits the alternatives in the other. The extremes in the categories of testing that may be considered are no testing, internal and external manual testing, and internal and external semiautomatic and automatic testing.

No testing, which is an extreme situation, is the discarding of equipment or systems upon detection of failure during operation. The factors to be considered in a "no test" decision are maintenance time, economy of a discard-at-failure maintenance concept, and availability of replacement equipments/systems to support the philosophy. The no-testing philosophy is seldom used during discard-at-failure maintenance. Rather, failure of a part is validated by a separate test before the part is discarded.

Internal and external manual testing involves the use of either internal or external manual test equipment to detect, locate, and isolate failures. Automatic testing is the use of methods that detect, locate, and isolate failures without the attention of maintenance personnel; semiautomatic testing requires the attention of maintenance personnel to go from step to step within the process. In the case of manual testing, maintenance personnel must use their capabilities to perform the detection, localization, and isolation of failures and perform these functions manually.

In either automatic, semiautomatic, or manual testing, the factors to be considered in a test category decision are maintenance time, test equipment development time and cost, operational plan of deployment of each item, amount of testing to be performed (maintenance load), readiness requirements of prime equipment, maintenance level involved, simplicity and complexity of the test equipment, and training costs.

The test equipment selected in the categories discussed in par. 9-2.3.1 may be either internal or external. Internal test equipment, usually referred to as built-in test equipment, in the majority of cases is special-purpose equipment. It is built to perform a specific test function (or functions) on a particular piece of equipment. External test equipment may be either general-purpose or special-purpose. General-purpose equipment is built for general test functions.

Factors which the maintenance engineer should consider in test equipment selection are delineated in Table 9-7.

TABLE 9-7. FACTORS IN TEST EQUIPMENT SELECTION (Ref. 14)

Factor	Element	Rating: Built-in	Rating: Special-purpose	Rating: General-purpose
Maintenance technician	Personnel acceptance	High	Medium	Low
	Personnel safety	High	High-medium	Medium-low
	Complexity of test equipment operation	Low	Medium	High
	Time to complete tests	Least	Medium	Most
	Personnel training time	Least	Medium	Most
	Tendency to overdepend on test equipment	High	High	Low
Physical factors	Limits on size of test equipment	Minimum limits; depends on prime equipment and application		Maximum limits; limited by portability
	Limits on weight of test equipment	Minimum limits; depends on prime equipment and application		Maximum limits; limited by portability
	Complexity of "wiring in" test equipment	High	High	Low
	Need for additional test points in prime equipment	None	None	Many
	Wanted space in work areas	Least	Some	Most
	Storage problems	None	Medium	Many
	Need for traffic considerations	Low	Medium	.High

TABLE 9-7. FACTORS IN TEST EQUIPMENT SELECTION (Ref. 14) (Cont'd)

Factor	Element	Rating: Built-in	Special-purpose	General-purpose
Maintainability and reliability	Probability of test equipment damage	Low	Low	High
	Probability of damage to prime equipment caused by testing	Low	Low	High
	Effect on prime equipment operation of repairing test equipment failures	Some	Slight	None
Logistics	Cost to incorporate test equipment	High	Medium-high	None
	Test equipment procurement time	High	Medium	Low
	Design engineering effort	High-medium	High-medium	Low
	Compliance of test equipment with same specifications as prime equipment	Must	May	May
Application	Advantage of long duration and high-frequency usage in given location	High	High-medium	Low
	Versatility of application	Low	Low	High
	Opportunity for incorrect usage	Low	Low	High
	System adaptability to new test equipment	Low	Medium	High

9-2.5 TRADE-OFFS TO BE CONSIDERED IN TEST EQUIPMENT SELECTION (Ref. 12)

The maintenance engineer, through the overall process of the maintenance analysis, is confronted with the problem of deciding upon the selection of an optimum configuration from among several alternatives. As a result, the maintenance engineer becomes intimately involved and a key contributor in the overall trade-off process. In considering the total maintenance support aspects of the system, the maintenance engineer is concerned primarily with the maintenance concept, the maintenance environment, and the maintenance personnel. These major factors are the underlyiqg baseline for identification and selection of the test equipment. Identification and selection of the test equipment is complemented through the process of trade-offs. The term trade-off, as it relates to the decision process, is defined as the procedure by which several feasible alternatives are evaluated to provide the basis for selection of optimum configuration based on cost, performance, or a combination of parameters. The basic trade-off is accomplished in four steps: (1) definition of the problem, (2) description of the feasible alternatives, (3) evaluation of the alternatives, and (4) application of the results.

The test equipment for materiel may range from manual test equipment to more elaborate and complex automatic test equipment. The complexity of the military systems requiring detailed and extensive monitoring and checking to insure performance virtually has eliminated the manual, step-by-step, probing type of testing. More stringent requirements related to operational availability of equipment, minimum downtime of equipment, and reaction time, combined with the decrease in skills available, dictate that the prime consideration in relation to test equipment for materiel be the man-machine interface.

9-2.5.1 Man-machine Interface

In the man-machine interface, the basic consideration is the optimum combination of operational/maintenance functions to be accomplished by the man or machine. This interface is a key parameter, for it is the one on which all decisions are based. It considers not only the type, complexity, and capability of the materiel, but also the availability, skill requirements, and capability of the maintenance man to insure optimum performance and availability of equipment in the user environment. In this respect, the general steps related to both the operational and maintenance procedures must be considered.

Operational procedures vary among different types of equipment; however, related to manual testing of equipment, the maintenance technician normally will be required to use his ingenuity to interface various items of prime and test equipment to provide a desired configuration for test, and to consult the technical manuals or detailed test procedure manuals during the total test process.

In automatic testing, generally all of the maintenance steps except replacement of defective parts are accomplished automatically. In this case, the basic reference, instead of a technical manual is a punched tape, a stack of punched cards, or a computer memory into which complete test procedures and acceptable limits have been compiled. Programmable switching networks and fault isolation routines and subroutines normally are controlled through software programming. Semiautomatic testing requires human intervention during automatic testing to activate controls or switches and continue program operation from predetermined monitoring points, program stops, and/or flags. The trend today, based on complexity of equipment and skill level of personnel, is to minimize the human actions required for operational and maintenance testing by the use of automatic test features.

9-2.5.2 Automatic Testing

Maintenance testing and checkout of complex systems can be accomplished by one or more of several testing concepts; e.g., system level operational tests and definitive tests at the equipment and component level. System operational tests usually are performed in an operational environment and are dynamic, closed-loop tests. The equipment and component tests normally are performed in a maintenance environment and usually are static, open-loop tests. The decision to use these tests, or combinations thereof, is based on consideration of the following factors: test information and readout instrumentation required for fault detection and isolation; depth of test in relation to system hardware level breakdown; maintenance levels at which the tests are to be performed; the time permitted for the tests; personnel training and skill requirements; acquisition cost; and maintenance, calibration, and support equipment requirements.

The decision regarding the particular type of test equipment to be used for system monitoring and maintenance must be made in the early stages of equipment design, in conjunction with the definition of repair policies and overall maintenance plans. The factors involved in the decision include the mission and operational characteristics of the equipment (reliability and availability), personnel resources, operational environment, logistic support requirements, development quantities and time, and cost. Trade studies should be made before incorporation of automatic test equipment in new designs is specified since, as a general rule, automatic test equipment should be considered only when one or more of the following conditions prevail: turnaround time or downtime must be held to an absolute minimum; many repetitive measurements must be made; availability and readiness test requirements dictate its use; and maintenance loads warrant its use.

Fault isolation time averages 60 percent of the total active repair time in electronic systems; therefore, efforts to reduce the active repair time and the number of personnel required is a key factor in reducing overall system cost. Studies regarding the use of computer-controlled test equipment indicate the following general advantages: total system cost savings; reduction in manpower for unit-under-test diagnostics; reduction in technical skill requirements; reduction in training costs; increase in materiel readiness, system effectiveness, and cost effectiveness; and reduction in the test and repair time portion of the total downtime. Both computer-based systems and separate computer-controlled test equipment have been developed and successfully used. In the decision process, the maintenance engineer should consider the applicability of these techniques to perform the materiel test function.

Three major trade-off areas for automatic versus manual test equipment are:

a. Level of test: the trade-offs required to define the depth of penetration of each test function in the equipment.

b. Degree of test equipment automaticity: the trade-offs required to define the details necessary to implement automatic testing, usually involving determination of how the test equipment should be programmed (punched tape, manual setup of parameter values by operator, magnetic drum); how test results should be displayed (go/no-go indicators, meters, color-coded readout, etc.); and whether testing should be stopped when an out-of-tolerance condition is detected or should branch automatically into an isolation routine.

c. Extent of built-in test equipment: the trade-offs necessary to optimize built-in test equipment in terms of its design configuration and complexity.

9-2.5.3 Resource Requirements, Operational Availability, and logistics

In the overall trade-off process, maintenance engineering not only should consider the test capability of TMDE in relation to the prime equipment, but also should consider the maintenance support demands imposed by the TMDE itself and TMDE impact on system performance. Reliability, maintainability, durability, transportability, calibration requirements, and other parameters that affect operational availability and support costs are traded off. This is required because weapon system availability depends, in part, upon TMDE availability, and pne portion of weapon system life cycle costs consists of all costs associated with the operation and maintenance of TMDE.

The operational availability of TMDE is a function of its reliability, maintainability, and the closely related parameter, durability. These parameters determine the frequency with which TMDE maintenance (including calibration) is performed and the resources (personnel, facilities, additional test equipment, etc.) required to perform the maintenance.

TMDE that is not built-in can impact system operational availability, even though the TMDE is operating properly. The impact can result from time lost during test setup and/or preparation and, if the TMDE normally is not stored in the immediate vicinity of the prime equipment, from time lost during transportation. Maintenance engineering should insure that the prime equipment and the test equipment are designed to provide simple, foolproof methods for any required test setups. Also, careful consideration should be given to proposed TMDE storage locations and TMDE transportation times that will be required in an operational environment.

TMDE must be transported, either as an entity or as part of the prime equipment, from the point of manufacture to the point of use, and subsequently to support the prime materiel and to be maintained. Thus, it generates logistic requirements and costs. Some test equipment, by its inherent nature, is not considered transportable unless special handling and transportation factors are considered. In the overall trade-off process, the factors of handling and transportation, as well as the factors mentioned previously, must be considered. Handling and transportation considerations include the requirements for special containerization (i.e., shock mount provisions for delicate meters, special containers for handling and transportation of test equipment, unitized packaging of the test equipment versus separate packaging, etc.) and the mode of transportation, with its subsequent environmental consideration of shock, vibration, and temperature. Included in the transportation factor is consideration of the total mobility of the test equipment, whether an integral part of the prime equipment or a separate item of test equipment that the maintenance technician must obtain from some remote location in order to perform diagnosis and troubleshooting on the prime item. Some of the considerations related to mobility are:

a. Mode of transportation– aircraft or truck

b. Method of handling–handcarried, special handling equipment

c. Environment for usage–shop facility, deployed systems

d. Environmental obstacles–terrain, prime equipment constraints (i.e., steps, doors, space restrictions, accessibility, etc.).

Test equipment calibration requirements comprise another important logistic consideration for maintenance engineering. Identifying these requirements and providing a calibration capability at the time the weapon system is deployed are equally as important as insuring that all of the weapon system support equipment is available when the system is deployed. This is true because regulations forbid the use of uncalibrated TMDE that requires calibration. Moreover, uncalibrated TMDE inherently is incapable of performing its function properly. Without a required TMDE calibration capability, weapon system availability becomes zero the first time the prime equipment requires calibration.

TMDE calibration requirements are associated closely with tolerance requirements established for operation of the prime equipment. Normally, it is not feasible to eliminate TMDE calibration requirements. However, with proper planning, sometimes it is feasible to minimize the requirements, For example, materiel production acceptance test tolerances frequently are more stringent than those required for adequate testing of deployed materiel. If the production acceptance tolerances are accepted as field test tolerances (as sometimes occurs), TMDE operating and calibration tolerances will be stringent. On the other hand, if it can be demonstrated early in a materiel program that relaxed production test tolerances are acceptable for field use, TMDE costs may be less than they would have been otherwise, and calibration requirements may be reduced. Additionally, the durability of the prime materiel probably will be affected favorably.

To insure that a calibration capability exists when test equipment is deployed, initial calibration requirements are established during the weapon system conceptual phase. These requirements are submitted to the US Army Metrology and Calibration Center, which is the Army focal point for matters pertaining to calibration. The Calibration Center and Materiel Manager jointly establish calibration procedures, and the equipment requiring calibration is entered into TB 750-236, *Calibration Requirements for the Maintenance of Army Materiel.* After deployment, the calibration services are provided by the Army standard laboratory, Army calibration laboratories, area calibration teams, and/or specified direct and general support units (Ref. 19).

9-3 TROUBLESHOOTING TECHNIQUES AND AIDS

During the second quarter of FY75, the Assistant Secretary of Defense (Comptroller) stated that the FY75 DoD budget would approximate $88.7 billion and that military personnel costs would account for **$25.3** billion of the total. These figures compare reasonably well with the projections shown in Fig. 8-4. Military personnel costs are and will continue to be significant. The portion of these costs that is attributable to maintenance (technicians who devote full time and operators who devote part time to maintenance) is also significant. An improved transfer of information to personnel performing maintenance will decrease personnel costs and increase materiel availability. Personnel costs will decrease because qualitative and quantitative personnel requirements will decrease. Materiel availability will increase because maintenance time will decrease.

In the case of troubleshooting aids, the intent is to provide the technician with the information necessary to isolate the cause of the malfunction with a high degree of accuracy, in the shortest time, and with minimum effort. Troubleshooting aids should meet the following requirements:

a. Provide system definition by identifying the interface boundaries relative to associated systems, and by identifying the interrelationship of all parts within the system that are required to accomplish system performance.

b. State the preliminary condition of the system necessary to verify the symptom by identifying test setup requirements for malfunctioning and interfacing items.

c. State the relationship of the symptom to all possible causes by identifying the functional interrelationships of parts involved in producing the indication of malfunction.

d. Identify the location of all parts in the system to facilitate isolation of suspect parts.

e. Provide a functional description of the system and each part in the system to identify the specific performance characteristics of each part.

In the development of troubleshooting aids, based on a U S Air Force study, the originator. must be able to recognize and identify the functional relationship of parts within systems and subsystems within systems; be familiar with the structure, function, and schematic symbolizing of the parts; be capable of performing signal flow or circuit analysis; and be capable of documenting the results of the analysis to serve as an effective diagnosis and troubleshooting aid (Ref. 16).

The process by which documentation is produced to be available for the delivery of the equipment means that the preliminary maintenance manual normally is written before the equipment is produced and, although it reflects careful analysis of the task the technician is to perform, its use may be difficult. The cross-references in the documentation may involve the use of several separate documents or sections of a manual in order to perform the diagnosis and troubleshooting tasks.

Numerous studies on the format and content of maintenance information indicate that faster and better maintenance can be performed if technicians use job performance aids. These aids are documents or devices that give precise step-by-step instructions for each task, or otherwise present in a concise and consolidated manner all information relevant to a given task. The presentation or types of aids vary from detailed step-by-step procedures that require no human decisions to be made to those which provide the technician with a general understanding of the system/equipment/materiel and guidance in the decision-making process. Fully proceduralized aids have been developed for troubleshooting tasks (see Fig. **4-5**); however, most of the devices are designed to assist the technician in understanding the subsystem and formulating a strategy for isolating the fault or faults. Most of the decision aids include variations of the maintenance dependency charts (Ref. 15).

The maintenance dependency chart illustrates the dependency and interrelationship of all elements and functional entities within the equipment or system by use of symbols. The dependency charts provide the data necessary to diagnose and troubleshoot the equipment. The charts conform to the following criteria:

a. Show, by graphic means, all of the circuit interdependencies in such a manner as to facilitate troubleshooting.

b. Identify all significant checkpoints and indications necessary to troubleshoot the equipment. These are arranged in a manner which minimizes the number of checks that a technician must make to isolate a malfunction.

c. Present all signal data (waveforms, angular motions, timing, voltage, pressures, etc.) in a manner to facilitate their use in troubleshooting.

d. Relate key troubleshooting to procedural data (turnon, adjustment, calibration, operation, alignment, and performance check).

The maintenance dependency chart has particular significance when the signal flow diverges as a result either of switching actions or proper end item function, when signal flow occurs through separate but dependent paths, when signals converge either from separate sources or through separate paths, and when troubleshooting procedures are so complex that an extreme amount of verbal redundancy would be necessary to present all the information concerning the dependency of signal flow to describe the required operations (Ref. 16).

Three basic symbols represent the functional entities or circuit elements. The event box (☐) represents an action or availability of one or more events resulting from the proper operation of the functional entities associated with the event. The functional entity dot (•) represents a functional entity or a group of functional entities. The dependency marker (▲) indicates dependency upon another event. Variations of the basic symbols are used, consisting of the addition of nomenclature or various types of backgrounds to the basic symbols, to provide more detail information. The charts may be used for electrical, hydraulic, and mechanical equipment to depict simple, multiple-input, and multiple-output dependency lines; serial, parallel, and serial parallel relationships; parallel divergent or convergent-divergent branches; time delays; feedback loops; redundant dependency chains; and binary state symbols (Ref. 16).

Fig. 9-7 shows a simplified maintenance dependency chart. The schematic counterpart in the figure is depicted only to aid in the explanation of the maintenance dependency chart. The description of the circuit operation and maintenance dependency chart utilization is as follows:

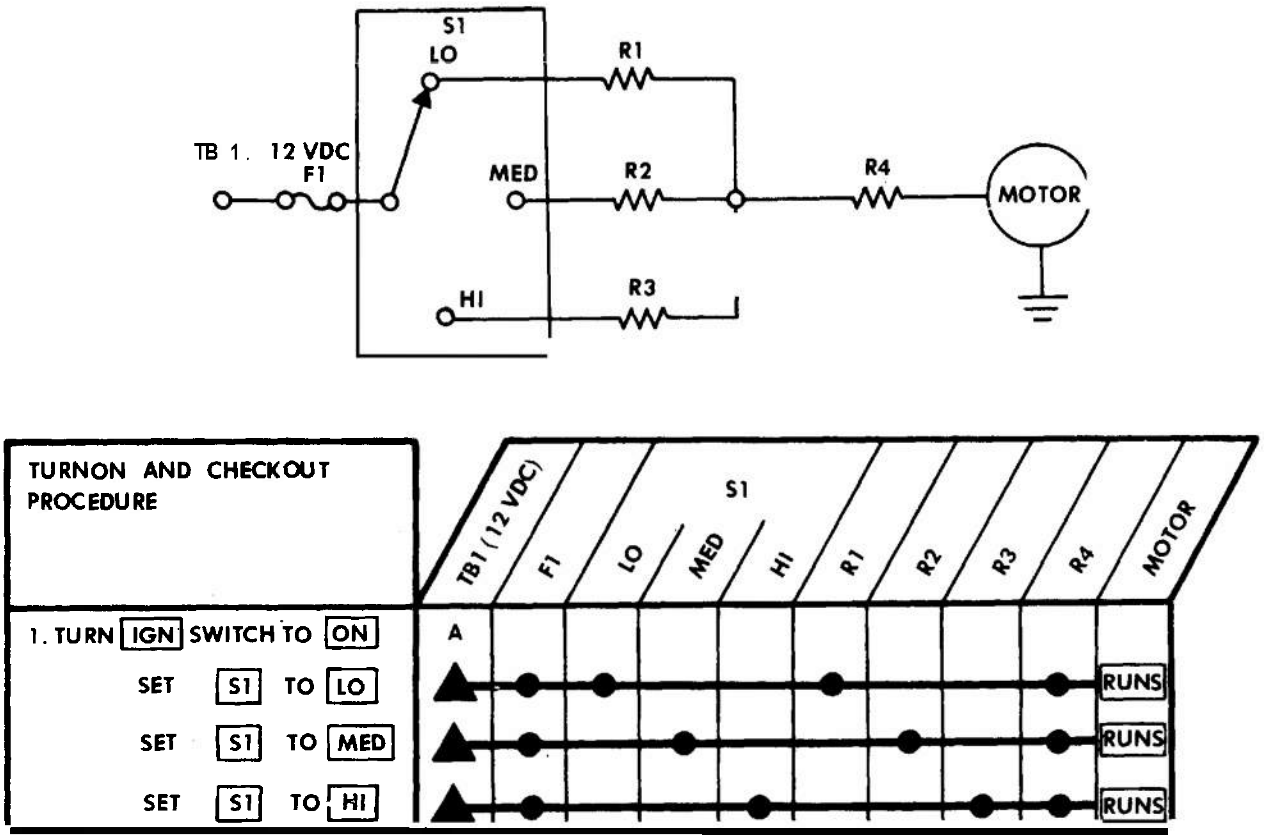


Figure 9-7. Simplified Maintenance Dependency Chart (Ref. 17)

When the circuit is energized, 12 VDC is present at TB1. This voltage is felt across fuse F1 and, depending on the position of switch S1, it will be present at R1, R2, or **R3,** R4, and the motor. There are four common components, TB1, F1, R4, and the motor. If any one of these components works in one circuit, it will work in every other circuit. If the switch is in the LO position, there is a circuit consisting of TB1, F1, LO contact of S1, R1, R4, and the motor. If the motor runs, all components of that circuit must be good. If switch S1 is turned to the MED position and the motor does not run, the faulty part must be either R2 or the MED contact of S1 because these are the only components that were not proven good. Set S1 to HI as a double check; the motor runs. Using the chart, work backwards. The motor ran when S1 was in both the LO and HI positions, and therefore the motor is good. If R4 was good for even one position, it must be good; notice that it is a common component. R3 must be good because it worked in the HI position. R2 is questionable because it is not a common component and cannot be proven good at this time. R1 is good because it worked in the LO position. The HI contact of S1 is good because it worked in the HI position. The MED contact is also questionable because it is not a common part and cannot be proven good at this time. The LO contact is also good because it worked in the LO position. Fuse F1 must be good because it worked in both LO and HI positions, and 12 V must be present at TB1 because the motor ran in the LO and HI positions. Therefore, the only two possibilities are R2 and the MED contact of S1. R2 would be the prime suspect. Basically, components common to more than one circuit are used to prove the component good or bad. Therefore, had the motor not run in any switch position, then a common component would have been suspected rather than a noncommon component as indicated in the example. (See Ref. 17.)

Troubleshooting aids are not required for every type of materiel. Malfunctions in some materiel, because of its inherent nature or use within the system, are detected as soon as they occur (e.g., malfunctioned tires, light bulbs, oil lines, etc.).

In the development of performance aids, both visual and audiovisual modes of operation have been considered. In efforts conducted in relation.to Project PIMO (Presentation of Information for Maintenance and Operations) the following conclusions were drawn (Ref. 18) from the U S Air Force study:

a. Learning is faster at the outset when using an audiovisual mode of presentation.

b. The audiovisual presentation provides a more complete presentation of the tasks, since both types of information are provided.

c. After the initial learning phase, the audiovisual mode inhibits the rapid response of the technician due to the fixed rate of presentation of the material.

d. The audiovisual mode is effective when it is important for the technician to have both hands free or when faster learning is important.

e. Audiovisual techniques have high potential for use either for selected jobs or on-the-job training, or when the individuals performing the troubleshooting are not familiar with the written language or have a very slow reading rate.

f. The use of visual devices versus the booklet or hard copy form basically is supported by the ease of storage, update, and data retrieval.

g. Cost in relation to both audiovisual and visual is a factor in comparison to the technical manual (hard copy) form of presentation.

REFERENCES

1. Technical Report No. 5, *A Compendium of Authenticated Terms and Definitions,* School of Systems and Logistics, Wright-Patterson AFB, Ohio, January 1970.
2. AMCP 706-134, *Engineering Design Handbook, Maintainabality Guide for Design.*
3. TM 38-750, *The Army Maintenance Management System (TAMMS),* November 1972.
4. MIL-HDBK-472, *Maintainability Prediction,* 24 May 1966.
5. DA PAM 700-21, *The Army Test Measurement and Diagnostic Equipment Register Index and Instructions,* December 1973.
6. AR 750-1, *Army Materiel Maintenance Concepts and Policies,* May 1972.
7. MIL-STD-1472A, *Human Engineering Design Criteria* for *Military Systems, Equipment and Facilities,* 15 May 1970.
8. AD-852 101, *PIMO Final Report Summary,* **Volume I,** May 1969.
9. AR 310-25, *Dictionary of United States Army Terms (Short Title: AD),* 1 June 1972.
10. AD-905 784, *Military Occupational Specialty Training Cost Handbook (MOS);* **Volume I,** *Enlisted MOS's,* November 1972.
11. AR 611-201, *Personnel Selection and Classification Enlisted Military Occupational Specialties, 28* December 1971.
12. NAVORD OD 39223, *Maintainabality Engineering Handbook,* 15 June 1969.
13. AR 750-43, *Test, Measurement and Diagnostic Equipment (To Include Prognostic Equipment and Calibration Test/Measurement Equipment),* 26 March 1974.
14. AFSC DH 1-9, *Maintainability,* December 20, 1973.
15. AD-758 713, *Improving DoD Maintenance Through Better Performance Aids,* March 1, 1973.
16. AD-852 107, *PIMO Troubleshooting Aid Preparation Guidelines,* May 1969.
17. *Equipment Manuals Maintenance Data Techniques,* AMC, Maintenance Support Center, February 1972.
18. AD-852 103, *PIMO Operational Systems Analysis,* **Volume 111,** May 1969.
19. TB 750-25, *Army Metrology and Calibration System,* 27 August 1971.

CHAPTER 10
MAINTENANCE FACILITIES

This chapter addresses several aspects of Army maintenance facilities. Maintenance facilities provided at all levels of maintenance and contractor facilities available to the Army are described. Maintenance facility development, work flows, and determination of capital equipment requirements are discussed.

10-1 INTRODUCTION

The U S Army Materiel Command (AMC) performs assigned materiel functions of the Department of the Army, including research and development, product engineering, test and evaluation, procurement and production, inventory management, storage and distribution, and maintenance. In addition, it provides for managerial and related service support to U.S. and foreign customers and provides worldwide technical and professional guidance and assistance to customers. The AMC headquarters provides policy direction for command operations. Individual installations and activities reporting either to AMC or to major subordinate commands actually carry out the Army's materiel program. These range from depots, maintenance shops, laboratories, arsenals, schools, test ranges, and CONUS proving grounds to worldwide logistic assistance and logistic management offices.

10-1.1 U S ARMY MATERIEL COMMAND COMMODITY MANAGEMENT

AMC currently accomplishes Army commodity management through six commodity commands. These commands accomplish research, development, production, procurement, cataloging, maintenance, standardization, supply control, new-equipment training, industrial readiness, and other functions vital to their commodity categories. The commodity commands are:

a. U S Army Armament Command (ARMCOM). This command is responsible for integrated commodity management of nuclear and non-nuclear munitions, weapons and weapon systems, turrets/cupolas and mounts, fire control equipment, rocket and missile warhead sections, demolition materiel, offensive/defensive chemical materiel, propellant actuated devices, training equipment and special tools, and test, measurement, and diagnostic equipment.

b. U S Army Aviation Systems Command (AVSCOM). This command is responsible for integrated commodity management of Army aircraft and aerial delivery equipment.

c. U S Army Electronics Command (ECOM). This command is responsible for integrated commodity management of communications, avionics, radar, automatic data processing, meteorology, night vision, combat surveillance, target acquisition, navigation and electronic warfare equipment, and the technology and devices necessary for operation and support of all of these.

d. U S Army Missile Command (MICOM). This command is responsible for integrated commodity management of assigned rocket, missile, and related programs.

e. U S Army Tank-Automotive Command (TACOM). This command is responsible for integrated commodity management of construction equipment and of tactical and combat vehicles. It also exercises responsibility for design, development, procurement, production, maintenance, supply, and repair part support of the Armed Forces vehicular fleet.

f. U S Army Troop Support Command (TROSCOM). This command is responsible for integrated materiel management of barriers and bridging, water purification equipment, power generators, fuel handling equipment, industrial engines and turbines, environmental control equipment, rail, marine, and amphibious equipment, and missile support equipment. Through field elements, it additionally provides Army class management for primary items of foods, food systems, clothing, industrial supplies, and automotive and construction equipment repair parts. The mission is oriented to the improvement of the personal and environmental needs of the field soldier.

In addition to the commodity commands, AMC has a major command that specializes in testing. This is the U S Army Test and Evaluation Command (TECOM), whose mission is to perform development tests of Army materiel and to provide test and evaluation support to the commodity commands.

To support the AMC commodity commands in the maintenance of materiel, **14** depots and **3** depot activities currently are located within CONUS. These installations, functioning under control of the Commander, AMC, are responsible for the receipt, storage, and issue of supplies and equipment for CONUS installations and designated oversea commands. The depots are assigned a depot mission by categories of equipment. The depot maintenance mission generally encompasses the following functions: overhaul, modification, conversion, repair, manufacturing, fabrication, calibration, and technical assistance. For ammunition, it encompasses demilitarization, renovation, and surveillance.

The depots within the AMC logistic complex include five general supply depots, three ammunition depots, and nine general-purpose (combined general supplies and ammunition depots, including three ammunition depot activities). A depot activity differs from a depot in that the depot activity has a reduced mission and is administered and funded by a depot to which it is satellited, rather than by Hq. AMC. The depots, depot activities, and their geographic locations follow:

a. General supply depots

(1) Corpus Christi Army Depot, Corpus Christi, TX

(2) New Cumberland Army Depot, New Cumberland, PA

(3) Sacramento Army Depot, Sacramento, CA

(4) Sharpe Army Depot, Lathrop, CA

(5) Tobyhanna Army Depot, Tobyhanna, PA

b. Ammunition depots

(1) Savanna Army Depot, Savanna, IL

(2) Seneca Army Depot, Romulus, NY

(3) Sierra Army Depot, Herlong, CA

c. General-purpose depots

(1) Anniston Army Depot, Anniston, AL

(2) Letterkenny Army Depot, Chambersburg, PA

(3) Lexington-Blue Grass Army Depot, Lexington, KY

(4) Pueblo Army Depot, Pueblo, CO

Ft. Wingate Army Depot Activity, Gallup, NM

Navajo Army Depot Activity, Flagstaff, AZ

(5) Red River Army Depot, Texarkana, TX

(6) Tooele Army Depot, Tooele, UT

Umatilla Army Depot Activity, Hermiston, OR

The general missions of the AMC CONUS depots are, as of date of publication, shown in Table **10-1.**

10-1.2 DEPOT MAINTENANCE FACILITIES (Ref. 1)

The mission of a US Army depot embodies a share of the total supply and maintenance responsibility of the Army distribution system. In conjunction with the depot mission, the Commander, AMC, is responsible for establishing the AMC policy governing stock distribution, storage, and maintenance; approving all missions assigned to depots, and all depot-type missions assigned to other types of installations such as arsenals; and authorizing emergency changes or modification of depot missions as may be required.

10-1.2.1 Primary Depot Functions

A typical US Army depot in CONUS is concerned with receipt, storage, and issue of general supplies, equipment, and materiel for distribution to CONUS installations and to designated oversea areas. In addition, when required, a depot stocks mobilization reserve supplies. The depot also receives, segregates, identifies, classifies excess, and returns materiel for salvage, repair, renovation, storage, or other disposition. Included, normally, is the requirement to assemble units and components of equipment and materiel into sets, such as basic issue item packages, and to issue both major and minor items.

Designated depots are concerned with receipt, storage, and issue of commodities and items for other military services and Government agencies. In addition, they repair, overhaul, modify, fabricate, and rebuild Army items of equipment, weapons, and materiel, as well

TABLE 10-1. AMC DEPOTS AND MISSIONS (Ref. 1)

	Type of Activity	Mission
1.	Anniston Army Depot, Anniston, AL	Performs depot maintenance on ordnance-type equipment and ammunition—small arms, guided missiles, and chemical.
2.	Corpus Christi Army Depot, Corpus Christi, TX	Performs depot level maintenance on aircraft, aeronautical equipment, and avionics. Also performs calibration services.
3.	Fort Wingate Army Depot Activity, Gallup, NM	Performs surveillance and storage of ammunition.
4.	Letterkenny Army Depot, Chambersburg, PA	Performs overhaul, repair, modification, and field maintenance support on ordnance-type supplies, equipment, and ammunition—chemical, guided missiles, and fire control.
5.	Lexington-Blue Grass Army Depot, Lexington, KY	Provides the maintenance functions of inspection, quality control, testing, calibration, modification, overhaul, and repair of signal-type equipment. Performs renovation and maintenance of ammunition.
6.	Navajo Army Depot Activity, Flagstaff, AZ	Performs renovation and maintenance of ammunition.
7.	New Cumberland Army Depot, New Cumberland, PA	Performs depot maintenance on transportation-type materiel. Performs overhaul and general support maintenance on Army aircraft.
8.	Pueblo Army Depot, Pueblo, CO	Provides for overhaul, modification, rebuild of ordnance general supplies, and renovation of ammunition.
9.	Red River Army Depot, Texarkana, TX	Performs depot maintenance on ordnance-type general supplies such as field artillery, fire control materiel, small arms, vehicular armament mounts, combat and tactical vehicles and assemblies, vehicle secondary items, guided missiles, and conventional munitions.
10.	Sacramento Army Depot, Sacramento, CA	Performs overhaul, conversion, modification (including retrofit), repair, inspection, test, fabrication, and reclamation of electronic commodities, including components and systems; provides nucleonic services.
11.	Savanna Army Depot, Savanna, IL	Performs renovation and maintenance on conventional weapons, guided missile ammunition, and commodity groups.
12.	Seneca Army Depot, Romulus, NY	Performs renovation of chemical and ordnance ammunition and special weapons.
13.	Sharpe Army Depot, Lathrop, CA	Performs depot maintenance on chemical and transportation-type materiel; performs overhaul and general support maintenance on Army aircraft.

TABLE 10-1. AMC DEPOTS AND MISSIONS (Ref. 1) (Cont'd)

	Type of Activity	Mission
14.	Sierra Army Depot, Herlong, CA	Restores conventional, guided missile, and special weapon ammunition to a serviceable condition by maintenance usually requiring replacement of components and subassemblies.
15.	Tobyhanna Army Depot, Tobyhanna, PA	Performs major overhaul, modification, fabrication, and repair of signal-type items, engine generators, medical equipment, and transport vehicles. Maintains secondary reference standards and facilities and secondary transfer standards field service.
16.	Tooele Army Depot, Tooele, UT	Performs depot maintenance on ammunition, chemical, construction, rail, and general equipment, and guided missiles.
17.	Umatilla Army Depot Activity, Hermiston, OR	Provides renovation for ordnance and chemical ammunition.

as materiel and equipment of other Department of Defense agencies.

Depot ammunition requirements now encompass conventional, nuclear, missile, and chemical, biological, and radiological materiel. Many of the missions of depots that store general supplies also are applicable to depots that store ammunition. They receive, store, issue, demilitarize, and renovate ammunition, special weapon materiel, and both propellants and explosive components of guided missiles.

10-1.2.2 Miscellaneous Depot Functions

In addition to the missions already stated, the following related mission functions are performed by depots:

a. Establishing and maintaining quality assurance and surveillance programs for storage and maintenance activities

b. Conducting tests and experiments in methods of loading and storing material and in using material handling equipment

c. Developing materiel packaging standards and procedures, and conducting methodology studies of supply systems

d. Maintaining liaison with and providing technical assistance to military users of Army materiel

e. Providing command administration, management, logistic support, maintenance in-storage, and other related support and service activities for the depot.

f. Providing depot in-house maintenance engineering services. This function normally is accomplished in the Production Engineering Division (par. 10-1.2.3.2).

Depot functions are performed by either Table of Organization and Equipment (TOE).or Table of Distribution and Allowances (TDA) units. Some characteristics of a TOE unit are:

a. The unit is one that is required to perform combat, combat support, or combat service support missions.

b. The requirement for the unit is permanent.

c. The unit is designed for oversea deployment.

Some characteristics of a TDA unit are:

a. The unit is part of the fixed support establishment.

b. The unit's workload is subject to fluctuation.

c. At the time the unit is organized, there is no intention to deploy it overseas, *d.* Civilan personnel are required in the permanent structure of the organization.

e. Commercial, nontype-classified equipment is required for mission performance.

Examples of TOE organizations are infantry division, Army calibration company, general support field service company, artillery battalion, rifle company, etc. A CONUS depot organization typifies a TDA unit (Ref. 9).

Normally, depot maintenance is performed in TDA shops or under contract at commercial facilities. The primary purpose of depot maintenance is to augment stocks of serviceable materiel. Selected depots, however, are assigned the mission of performing depot maintenance on medical equipment and returning this equipment to the user on a nonreimbursable basis. Another exception to the general procedure is Army aircraft. Selected AMC depots are assigned the additional mission of performing general support maintenance on Army aircraft. Generally, the general support capability is provided to using units by special maintenance shops located in proximity to the using unit. These shops are administered by the director of maintenance of an assigned Army depot.

Most depot maintenance facilities have depot training programs. Participation in these programs, however, is not limited to depot maintenance personnel. In many instances, organizational, direct support, and general support maintenance personnel participate in these programs to receive instructions in repair and preventive maintenance techniques for new materiel.

Oversea depots and other activities with depot-type missions are controlled by the oversea commanders. Nevertheless, the missions. of oversea depots generally are similar to the missions assigned to CONUS depots. The same principles of supply and maintenance apply within a theater; therefore, the foregoing functions are valid equally for oversea depots and CONUS depots to **a** great extent.

The terms "branch depots" and "general depots" no longer are used to classify depots as to mission responsibilities. Neither is any distinction made for large depots that handle many types of commodities, smaller depots that handle a limited range of commodities, or depots that handle a single type of commodity such as ammunition. All depots presently are designated simply as Army depots. Civilian employees provide the bulk of the work force employed in CONUS depots, although there are a few TOE depot maintenance units of company and battalion size attached to some depots in CONUS. Oversea depots may consist almost entirely of TOE depot maintenance units, but they also employ large numbers of civilian personnel. Some depots have depot maintenance shops. The primary mission of these maintenance shops is to support supply on a return-to-stock basis. To accomplish this mission, depot maintenance shops use production line, bay shop, or bench-type methods of operation, as appropriate. These shops contain extensive facilities, specialized production equipment, and the most diverse technical skills in the Army maintenance system. Other depot operating personnel maintain close liaison with maintenance activities to insure that proper and adequate support is rendered and to provide for an orderly flow of work from lower categories of maintenance.

10-1.2.3 Basic Depot Organizations

The organizational structures of CONUS depots have been developed in accordance with basic concepts and policies. The inclusion, stature, names, and functions of organizational elements may vary among depots due to differing missions and scope of activities. A basic depot organizational chart is provided in Fig. 10-1. The maintenance element of depot organizations normally is a directorate that is equal in stature to the other elements shown. Divisions normally found within the Maintenance Directorate are the Depot Shop Division, Shop Supply Division, Production Control Division, and Production Engineering Division. These shops are described in the paragraphs that follow.

J0-J.2.3.J *Depot Shop Division*

The depot shop division is responsible for performing depot maintenance on all materiel and weapon systems. The work performed includes overhaul, progressive maintenance, conversion, activation, inactivation, analytical rework, modification, repair, inspection, test, and manufacture or fabrication of parts. Generally, this division includes all of the production shops, and it comprises approximately 90 percent of the civilian work force assigned to

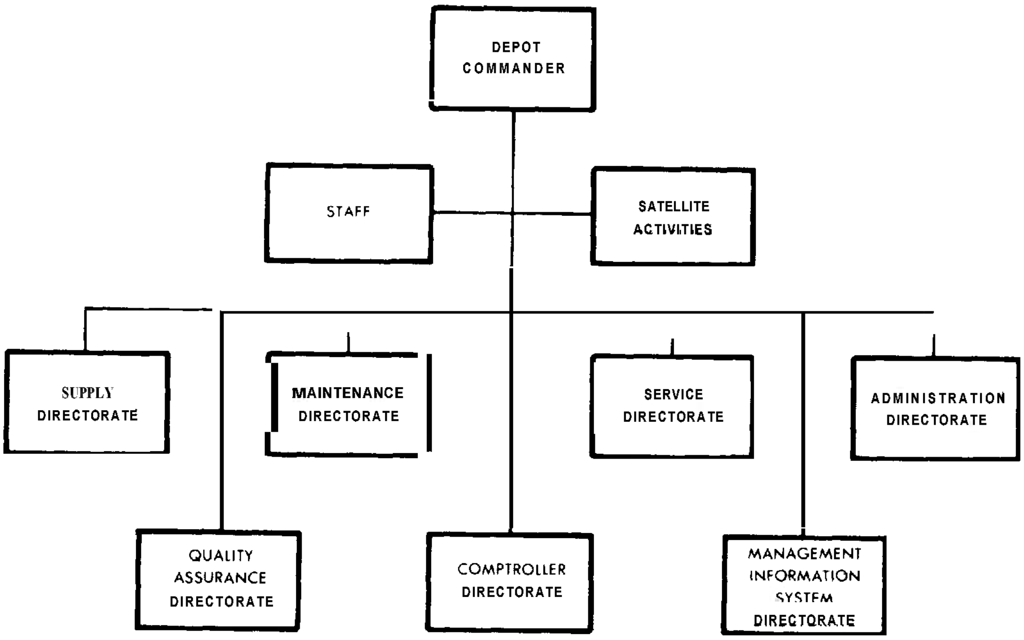


Figure 10-1. Basic Depot Organization

the Maintenance Directorate in CONUS depots. Depending on the maintenance mission of a depot, this division may include the shops that follow:

a. Wheeled vehicle repair shops

b. Tracked vehicle repair shops

c. Armament repair shops

d. Missile and electronic repair shops

e. Aircraft repair shops

f. Radio repair shops

g. Instrument repair shops

h. Tire repair (retreading) shops

i. Machine shops

j. Shop maintenance shops

k. Welding shops

l. Sheet metal and radiator shops

m. Paint shops

n. Steam cleaning shops

o. Sandblasting shops

p. Woodworking and plastic shops

q. Canvas shops

r. Chemical cleaning and plating shops.

Service shop activities may be incorporated into a general repair shop when the particular function of a service shop is peculiar to a maintenance activity associated with only one of the general repair shops. For example, if the depot maintenance mission calls for repair or overhaul of wheeled vehicles, but excludes all other materiel equipped with radiators or requiring sheet metal work, the sheet metal and radiator shop may be an integral part of the wheeled vehicle repair shop.

Typical facility requirements in relation to the commodity commands are shown in Table 10-2. As a general rule, equipment overhauled at the depots must meet the original specifications and tolerances; therefore, the required tooling and test equipment usually are similar to those used in original manufacturing and are highly specialized.

TABLE 10-2. TYPICAL COMMODITY COMMAND DEPOT FACILITY REQUIREMENTS

Commodity Command	Types of Tools	General Shops	Special Shops
ARMCOM	Heavy machine Special Electronic	Machine Cleaning/plating Armament Electrical Instrument Welding	Optical Clean rooms Explosive Beta X-ray
AVSCOM	Heavy machine Specialized jigs Special Electronic	Sheet metal Engine Transmission Paint Cleaning/plating Instrument Welding	Clean rooms
ECOM	Light machine Special Electronic	Electronic Electrical Sheet metal Cleaning/painting	Clean rooms Metrology Calibration
MICOM	Light machine Special Electronic	Missile (electronic) Sheet metal Machine Cleaning/plating Painting	Clean rooms Metrology Calibration Explosive
TACOM	Heavy industrial Electrical Electronic	Machine Cleaning/plating Painting Welding Canvas Sheet metal Instrument	Semiclean rooms
TROSCOM	Heavy machine Light machine Electrical Electronic	Fabric repair Instrument repair Painting Wood shop Sheet metal Machine Welding	Electric motor/generator Rewind

10-1.2.3.2 *Production Control, Production Engineering, and Shop Supply Divisions*

The operations of depot shops normally are supported by three other divisons. These divisions provide administrative and technical support required in performance of depot maintenance. The general responsibilities of these divisions are:

a. *Production Control Division:*

(1) Establish local depot maintenance workload schedules based upon direction from MIDA, commodity commands, and AMC headquarters.

(2) Assure coordination of various functions to assure that materiel and resources are available for successful accomplishment of maintenance programs.

(3) Provide feedback data to various local and AMC activities depicting status of maintenance programs.

b. *Production Engineering Division:*

(1) Determine facility and plant equipment requirements.

(2) Review depot maintenance work requirements (DMWR's) and other technical publications for technical adequacy and depot impact.

(3) Provide technical guidance for shop operations, including repair processes, shop layouts, etc.

(4) Coordinate work measurement programs (time standards) with other depot agencies.

(5) Coordinate the solution of calibration problems with other depot agencies.

(6) Coordinate the transmission of technical data on depot capabilities to commodity commands and other AMC activities.

(7) Maintain current knowledge pertaining to new maintenance engineering techniques.

c. *Shop Supply Division:*

Provide intrashop supply support—including transportation, receipt, segregation, reporting and requisitioning—to assure availability of required material and hand tools at required locations.

10-1.3 CONTRACTOR FACILITIES

In the early phases of production, during the overlap in production and deployment, the full facilities of the contractor, in relation to the deployed materiel, may be available for the support program. This includes the production line processes, engineering and technical support services, and field support. Upon full deployment, except in the cases of highly specialized materiel maintenance operations (e.g., gyros, optical equipment) requiring unique manufacturing processes and specialized facilities, the test and maintenance facilities of the contractor may be incorporated into the respective depot facilities of the AMC. This capability generally includes the "production line" type of test, diagnostic, and measurement equipment and special quality acceptance procedures. Except in the cases noted, the contractor's production line capability normally is phased out and limited capability for manufacture or repair is retained. Reactivation of these facilities and/or the capability for full capacity normally is a costly and time-consuming process.

In addition to the physical plant facilities, the contractor facilities, in the broad sense, may provide technical support services, contract field services, and personnel and training programs.

The technical support services relate to the investigation of reported problems on the deployed materiel as a result of a request from the user, the review of the technical data package for adequacy, and the determination of the solution to the problem. The solution may involve a change in design or in operation or maintenance procedures, or clarification in interpretation of the data package. Interfaces in the development of the solution include liaison with personnel associated with publications, training, field service, human factors, quality, logistic support, and design engineering; review of design, support, and operation and maintenance procedures; and failure analysis of equipment improvement recommendations.

The use of strategically located contract field service personnel minimizes the in-plant technical support service requirements. These personnel provide on-site expertise to assist in the resolution of user problems related to the fielded equipment.

The capability of the user to perform the designated materiel operation and maintenance functions basically is determined by the complexity of the equipment and the personnel and training program. Generally, the contractor provides the development and implementation of training courses such as staff planning, technical orientation, instructor and key personnel courses, and subsequent courses to provide for training related to materiel modifications or improvements.

10-2 TYPES OF FACILITIES AT ALL LEVELS OF MAINTENANCE

The Army maintenance structure normally is divided into four maintenance levels. However, levels are combined when it is cost-effective to do so, and aviation materiel and some other types are maintained with three levels. Maintenance levels relate maintenance operations to other military operations, facilitate assignment of responsibility for specific maintenance tasks for specific materiel to specific levels of command, and permit orderly and efficient distribution of maintenance resources.

Maintenance operations encompass the physical performance of tasks such as inspection, servicing, adjustment, alignment, repair, calibration, conversion, overhaul, rebuild, and modification of equipment. These operations are specified in the equipment publications for each item or commodity group and vary according to the maintenance concept for the item or commodity. The operations are performed by activities that use the equipment to accomplish their missions; by activities that are assigned the mission of performing maintenance operations in support of other activities, local area, and wholesale supply systems; and by commercial firms under contract or other military services and Government agencies as a result of interservice support agreements.

The types of maintenance operations performed by each of the Army maintenance levels and facilities required are discussed in subsequent paragraphs.

10-2.1 ARMY MAINTENANCE LEVELS

The majority of Army materiel is maintained with four maintenance levels: organizational, direct support, general support, and depot. Aviation materiel and certain other materiel are maintained with three maintenance levels. For aviation materiel, these levels are called aviation unit maintenance, aviation intermediate support maintenance, and depot maintenance. For the other materiel, the levels are called organizational, field, and depot. Essentially, aviation intermediate support maintenance and field maintenance units are responsible for combined direct support and general support functions.

Conceptually, aviation unit maintenance is identical to organizational maintenance. In each case, preventive maintenance, simple adjustments, tests and repairs, modular replacements, etc., are accomplished. The depot maintenance concepts for aviation and other materiel also are quite similar. Aviation intermediate support maintenance differs, of course, from either direct or general support maintenance. Therefore, the paragraphs that follow make no differentiation between organizational and aviation unit maintenance and depot and aviation depot maintenance, but 'separately discuss aviation intermediate support maintenance and direct and general support maintenance.

10-2.1.1 Organizational and Aviation Unit Maintenance (Ref. 2)

Each combat, combat support, and combat service support activity is authorized an organic materiel maintenance element (i.e., crew/operator and maintenance personnel) to perform authorized organizational maintenance operations on equipment assigned to or used by it to accomplish its mission.

The operations normally allocated to this level encompass:

a. Performance of preventive maintenance services; e.g., crew/operator checks and services, and scheduled maintenance services. These include visual and tactile inspections of external and other easily accessible components, lubrication, cleaning, preserving, tightening, and, except for communication and security materiel, minor adjustments to easily accessible mechanical, electrical, hydraulic, and pneumatic systems.

b. Diagnosis and isolation of equipment malfunctions that can be traced readily to defective modules (components/assemblies), using easy-to-interpret, built-in test equipment, simple goho-go indicators, installed instrumentation, or easy-to-use and easy-to-interpret external diagnostic/fault isolation devices such as automatic test equipment.

c. Replacement of modules (components/assemblies), except for communication security (COMSEC) materiel, on a time change basis or those identified as worn, damaged, or otherwise defective which can be removed/installed readily with easy-to-use tools, and which do not require critical adjustment, calibration, or alignment before or after installation.

d. Replacement of easily accessible unserviceable piece parts not requiring special tools or test equipment; e.g., knobs, lamps, fan belts, wheels, tires, filter elements, firing pins, gages, expendable antennas, and gun barrels.

e. Evacuation of malfunctioning end items and modules (properly preserved and tagged), which are beyond the authorized capability or capacity to repair or replace, to designated supporting maintenance facilities for repair or exchange for like serviceable items when these activities cannot provide the required support on site.

10-2.1.2 Support Maintenance (Ref. 2)

Combat service support units are authorized in the Army force structure to provide direct support, general support, and/or combined support maintenance services to the Army in the field. To the maximum extent practicable, these units are functionalized; i.e., organized to perform specialized maintenance tasks on equipment of several commodity groupings.

10-2.1.2.1 Direct Support Muintenunce (Ref. 2)

This level of maintenance is performed on equipment in the direct support unit area or, when practical and cost-effective, at the equipment operating site for return to user. The operations normally allocated to this level encompass:

a. Diagnosis and isolation of equipment/module malfunctions, and adjustment, calibration, and alignment of modules when these functions can be accomplished readily with easy-to-use and easy-to-interpret tools and test, measurement, and diagnostic equipment.

b. Repair of equipment by replacing:

(1) Defective modules (e.g., engine or power plant, transfer units, transmissions, motors, and compressors) when the replacement will provide a high degree of reliability and successful return of the equipment to a serviceable status without extensive post-maintenance testing, run-in, or adjustment.

(2) Defective piece parts such as vacuum tubes, resistors, relays, coils, transformers, wheel seals, and universal joints.

c. Establishment and operation of a direct exchange facility, to include the repair of designated unserviceable modules for direct exchange. Module disassembly and repair normally are limited to tasks requiring the cleaning and replacement of seals, fittings, other external replaceable parts and common hardware, and/or the application of authorized repair kits.

d. Performance of pollution evaluations of emissions from equipment powered by internal combustion engines and the necessary adjustment, replacement, or repairs to keep these emissions within established standards.

e. Performance of light body repairs, to include straightening, welding, sanding, and painting of skirts, fenders, body, and hull sections.

f. Provision of quick reaction materiel readiness and technical assistance support to organizational maintenance elements:

(1) By means of highly mobile contact teams to perform or assist in the performance of authorized maintenance, and to provide on-the-job training

(2) Through the use of direct exchange procedures and operational readiness floats.

g. Evacuation of unserviceable end items and modules whose repair is beyond the authorized capability and capacity to designated facilities of the same or higher levels of main: tenance, as appropriate.

10-2.1.2.2 General Support Muintenunce (Ref. 2)

Operations at this level are aimed primarily at the repair of end items or modules for return to the local area or theater stocks, or in support of the direct exchange program.

Operations normally allocated to this category encompass:

a. Diagnosis and isolation of equipment/module malfunctions to the internal piece part level and adjustment, calibration, alignment, and repair of equipment/modules as necessary when restoration of the equipment/module to the original manufacturer's tolerances or standards is not required.

b. Replacement of defective modules when such replacement is beyond the authorized capability of lower maintenance categories.

c. Repair of major modules by grinding, adjusting, or aligning such items as valves, seats, and tappets. (Extensive remachining or grinding that subsequently will require balancing or metallizing is not authorized.)

d. Repair of modules by replacement of internal and external piece parts when special environmental facilities are not required. This includes the replacement of printed circuit boards/cards constructed of conventional piece parts and selected solid state integrated circuits.

e. Performance of heavy body, hull, turret, and frame repair to include steel and aluminum welding, wood and machine cutting, pressing, shearing, sanding, and painting.

f. Provision of area maintenance support, to include technical assistance, on-site maintenance, and contact team support. Such support is provided on an exception basis when general support maintenance activities are also assigned a direct support maintenance role. This could occur when the density of supported units does not justify assignment of a direct support maintenance unit. Normally, such support is provided to, or at the request of, supported direct support maintenance units.

g. Collection and classification of unserviceable or abandoned Class VII materiel (less aircraft, ammunition, missiles, crypotographic, and medical materiel) for proper disposition.

h. Operation of a cannibalization point, when authorized, to augment the direct exchange and/or local area and wholesale supply system stocks.

10-2.1.2.3 Aviation Intermediate Support Maintenance

Aviation intermediate support maintenance is the single maintenance level between the aviation unit and the depot. Maintenance activities at this level normally encompass:

a. All maintenance authorized to be accomplished by aviation unit maintenance

b. Inspection, troubleshooting, repair, replacement, calibration, and alignment of components, modules, and end items that can be accomplished with available tools, test equipment, and skills

c. Authorized airframe repair and fabrication of parts

d. Determination of the serviceability of specified modules/components removed prior to the expiration of time between overhaul or finite life and performance of collection and classification services for serviceable/unserviceable materiel

e. Repair of materiel for return to user and/or to stock

f. Maintenance of authorized operational readiness float aircraft

g. Aircraft weight and balance inspections and other inspections beyond the capability of aviation unit maintenance

h. Aircraft recovery, air evacuation, forward maintenance support, on-the-job training, and technical assistance through mobile maintenance contact teams

i. Operation of a cannibalization activity in accordance with current directives

j. Evacuation of unserviceable materiel beyond the local repair capability to depot maintenance.

10-2.1.3 Depot Maintenance (Ref. 2)

Depot maintenance operations normally encompass:

a. Performance of:

(1) Overhaul of end items/modules

(2) Repairs to items which exceed the capability of the field army, or when manufacturing tolerances must be met and maintained, or when special environmental facilities are required (e.g., clean room, controlled temperature/humidity, special clothing)

(3) Nondestructive testing to determine the utility of removed used parts

(4) Special inspections and modifications of equipment requiring extensive disassembly or elaborate test equipment. These are performed, when practical, as part of cyclic overhaul or special depot maintenance programs.

b. Manufacturing of items and parts not provided by or stocked in the supply system when operational or cost-effectiveness considerations indicate the need for such service.

c. Provision of wholesale level direct exchange support for selected end items and modules.

CONUS depots and non-TOE depot maintenance oversea activities also perform depot maintenance operations at the operating site on end items and modules which–because of size, character of their operating installation, or criticality–cannot be evacuated conveniently to a depot maintenance facility.

10-2.2 FACILITY REQUIREMENTS

A facility is an item of real property such as a structure or real property installed equipment. Planning for materiel maintenance facilities for all maintenance levels begins in the conceptual phase. Estimated facility requirements and the personnel, heavy machine tools, special tools, test equipment, etc., required to man and equip the facilities are a part of the materiel development plan. As the program progresses, these requirements are refined, and at the appropriate time, facility modification and construction, training, and materiel procurement programs are initiated.

The paragraphs that follow discuss typical maintenance facility requirements at the various maintenance levels. The type of maintenance facility required at the organizational level is so closely associated with the materiel category assigned to the unit that generalizations are almost meaningless. General descriptions become more meaningful at the higher levels.

10-2.2.1 Organizational level Facilities

Ma ntenance facilities at the organizational level may be relatively elaborate or extremely austere, depending upon the materiel assigned to the unit. If the unit materiel does not require combat mobility, facilities are apt to be structures. If combat mobility is necessary, facilities may be structures during peacetime but, during combat, facility substitutes such as tents and trucks are most likely to be used. For example, a fixed air defense missile site prior to and during combat will have missile assembly and supply facilities, while an airborne infantry unit may have maintenance and supply structures during peacetime but, during combat, will have at best maintenance and supply tents.

One materiel category common to most organizations is vehicles. The minimum facilities required for adequate organizational vehicle maintenance are:

a. A hardstand adequately drained and large enough to park unit vehicles and store other unit equipment

b. Availability of an adequate number of bays in a maintenance shop/shelter (heat and light desirable)

c. Availability of a wash rack

d. Availability of a grease rack/pit

e. Availability of tire repairing and battery charging facilities.

10-2.2.2 Direct Support level Facilities

The maintenance facilities required at the direct support level of maintenance are more elaborate than those required at the organizational level. However, due to the operational necessity that direct support units be 100 percent mobile, a major portion of the mission equipment of the unit is vehicular-mounted and mechanics work out of unit maintenance trucks and vans.

The maintenance facilities required at the direct support level in addition to those required for organizational maintenance include:

a. An adequate road net within the area to facilitate ease of movement under all climatic conditions

b. **A** hardstand for customer parking and equipment awaiting the shop *c.* Adequate heated and lighted maintenance areas

d. Adequate warehouse space for technical supply and direct exchange operations.

10-2.2.3 General Support level Facilities

The maintenance facilities required at the general support level are more elaborate and less mobile than those at either the organizational or direct support level. The general support maintenance company is not mobile in the true sense of the word and does a major portion of its work inside, using organic tentage and any permanent or semipermanent large buildings available.

The maintenance facilities required at the general support level include:

a. A large hardstand to accommodate a considerable backlog of repairable equipment.

b. Extensive shop and warehouse space to facilitate either a bay or production line method of operation.

10-2.2.4 Aviation Intermediate Support Maintenance Facilities

Facilities for aviation intermediate support maintenance are similar to those described for general support maintenance. Typical facilities include a hardstand and permanent or semipermanent structures to house TMDE and supplies and to provide maintenance work areas.

In the absence of permament structures, as would occur when deployment in undeveloped areas is required, initial facilities probably would comprise semipermanent structures and/or tents augmented with shop vans. Such facilities would be improved as permitted by the tactical situation.

10-2.2.5 Depot level Facilities (Ref. 3)

Each major Army materiel category – aircraft, missiles, etc. – is divided, by subsystem, into logical workload groups. Depots are divided into production shops that are equipped ,specifically to maintain assigned workload groups. These shops consist normally of relatively large, permanent structures. Examples of shop functions and shop equipment are shown in Table 10-2.

10-3 MAINTENANCE FACILITY WORK FLOW

Effective materiel maintenance management includes the work scheduling, establishment of orderly work flows, and verification of the quality of 'the maintenance performed. These management functions are applicable mainly to the field and depot maintenance levels.

10-3.1 FIELD SUPPORT MAINTENANCE WORK FLOW

Field maintenance operations conducted by mobile or semimobile Table of Organization and Equipment (TOE) military units are to be distinguished from those support activities conducted by civilian-manned fixed shops in CONUS or certain oversea areas. In distinguishing these two activities, the vital role which fixed shops play in providing field maintenance support to the field armies in CONUS or overseas should not be minimized. However, much field maintenance, especially in theaters of operations, primarily is a military operation in which TOE units play the dominant role. It must be recognized, when reference is made to general support, that in peacetime non-TOE fixed shops often provide this support to using and direct support units in lieu of TOE general oupport units. This situation is true particularly in CONUS garrisons and to some extent in communication zones. Furthermore, many of the functional organization and shop management practices followed in fixed shops are common to both direct support and general support TOE units.

10-3.1.1 Identifying Requirements and Instituting Repairs

The using unit has primary responsibility for identifying failures and for determining what deficiencies are beyond the capability of organizational maintenance. The cognizant direct support unit has primary responsibility, in such cases, for determining the extent and type of field maintenance required and the place and time at which this field maintenance will be performed. The specific methods by which these responsibilities are exercised will vary with local environmental and tactical conditions, the type of equipment, and the particular standing operating procedures of the user and supporting units. The initial identification of failure may be made by the operator, and then reported to the organizational mechanic. If the failure is beyond the established capability of organizational maintenance, the direct support unit can either:

a. Request that the item be brought in for repair or exchange by the using unit or by the recovery team of the direct support unit.

b. Send out a mobile repair team to perform on-site repairs or replacement.

c. Send out an inspector if there is a question as to repair action required. This does not mean that this decision-making process occurs for each incident of failure. Most types of maintenance deficiencies are repetitious, and once a suitable method of repair or evacuation is established for a given type of failure, it usually will be followed as a matter of prescribed routine.

The direct support company headquarters is responsible for deciding which course of action to follow after receiving a report from the line battalion. In many combat situations, the mobile repair teams or direct support platoons are operating in the field and, if they are on the command communication net or in physical contact with the user units, they may receive the failure reports directly. However, even in these cases, the mobile repair team ordinarily reports this information to its headquarters before undertaking any extensive repair or evacuation operation. In combat situations, communications among the users, the mobile repair teams, and the parent direct support unit must operate efficiently. It also must be understood clearly what communications are authorized directly between user units and the forward mobile teams and also what authority has been delegated to the mobile teams regarding when, where, and how to make repairs.

The direct support company headquarters or its forward direct support platoons, when designated, after receiving a report or examining the failed item, will determine whether field maintenance will be performed on site or at the company shops, and whether it will be performed by direct exchange or by repair and return to user. Smaller items or major components which break down in the forward company combat zones are replaced on site by direct exchange, and the item or component is repaired and returned to stock. During combat, a major piece of equipment—such as a truck, tank, or field radio set—usually is evacuated by the line battalion out of the immediate combat zone. Thus, any on-site repair or replacement made by the direct support unit actually is at the site of the battalion evacuation point rather than at the actual point of failure. This practice, when feasible, is preferred, since it enables the mobile repair teams of the direct support unit to operate in relative safety. However, in some cases, a mobile repair team operating in the combat zone may move up to the combat area of an infantry or armor company and perform an emergency repair or replacement at or very close to the point of equipment breakdown.

The mobile repair teams are a critical asset that must be used prudently by the direct support unit commander. It is essential that a priority system be established for their employment in order to maximize their utility. Although all TOE equipment and units presumably are essential to combat, some are more essential than others. A direct support unit commander, his operations officer, and the direct support platoon leaders must be familiar with the combat criticality of various equipment and of the units they support, so that during an exercise or combat, the highest priority jobs will receive the most prompt service by mobile repair teams. Similarly, a job priority system must be established for repairs that are to be made back at the direct support shops. Priorities may have to be revised during combat to meet changes in the tactical situation; nevertheless, a field maintenance unit, which at least commences a combat operation with a basic priority system, will be able to fulfill its support mission far better than a unit that operates on a first-come, first-served basis.

10-3.1.2 Evacuation of Unserviceable Items

The using organization is responsible for the evacuation of unserviceable materiel that is beyond the authorized organizational maintenance capability to the next higher maintenance level. The organization normally is responsible for accomplishing all required maintenance within its capability before evacuating an item that will be repaired and returned by a higher maintenance level. This organizational maintenance is not required on items that are evacuated to a higher maintenance level for repair, overhaul, or rebuild on a nonreturn basis. In preparation for either type of evacuation, the organization is responsible for accomplishing prescribed preservation, packaging, and packing of the materiel. Direct support units assist organizations, as necessary, in accomplishing materiel evacuation.

10-3.1.3 Maintenance Floats

Maintenance float is a quantity of major items required and authorized for stockage at field maintenance units and activities to provide replacement for unserviceable items of equipment when repair of unserviceable items and return to the user cannot be accomplished within a specified time. Maintenance floats have assumed increasing importance in field maintenance—especially in direct support operations—because they permit immediate exchange of serviceable items for unserviceable items and enable a using unit to perform its assigned mission without serious interruption. The use of floats also enables a field maintenance unit to complete repairs back at the shop with less urgency and, in combat, with more freedom from the press of battle. Since floats must allow for repair and turnaround time, they are limited to high density or critical mission items lest they become too costly and burdensome to the logistic system. Maintenance floats are computed by the major commands; information concerning the operation of the float system and authorization of specific items for stockage at direct and general support levels is contained in major command supply bulletins.

10-3.1.4 Internal TOE Shop Operations

The operation of a TOE field maintenance shop follows the basic principles of a fixed shop. The shop practices will vary because of differences in operating environments and the nature of mobile and semimobile shops versus fixed shops. There is likely to be greater flexibility and informality in TOE shop operations. Scheduling, which is difficult enough to accomplish at fixed shops, is almost impossible at TOE maintenance units. Stability in layout of supply and shop vans is complicated by mobility requirements and site selection problems. The restricted physical nature of direct support unit facilities and, to a lesser extent, general support units also creates a different working environment from that existing in fixed shops. In a theater of operation, combat conditions greatly affect TOE maintenance internal shop operations, causing more frequent movements, erratic supply, and disrupted communications with using units and other logistic units. Despite these various and unique problems encountered in internal TOE shop operations, the shop practices are reasonably standardized. The vans or tents are arranged, whenever possible, in a manner similar to a fixed shop, with provision for shop supply and for bay shop type repair. The vans or tents usually are set up on a functional basis, with separate vans or bays set up for specific types of repair. Dispersion also must be a factor in arranging shops.

10-3.1.4.1 Site Selection and Shop Luyout

The selection of a site and layout for TOE field maintenance shops depends upon the tactical situation, environmental conditions, the mobility of the unit, the TOE, the mission, and the availability of resources. A direct support unit will move its vans to an area selected by the unit commander (with the concurrence of the cognizant tactical commanders) to insure optimum service to the user units and protection for the maintenance unit. General support units also are located subject to tactical requirements and usually also take advantage of available local buildings in which shops can be set up. The layout of shops is determined largely by the TOE that establishes the shop sections and the authorized repair equipment. Considerable discretion rests with the unit commander in arranging his vans and tents, or in laying out a building. Generally, the shop office and/or operations section is located nearest to the shop or equipment pool area, since this usually is where initial and final inspections are made. The shop supply section should be located centrally and conveniently with respect to the repair sections. A commander should also use terrain and dispersion to their best advantage as a protection against conventional and nuclear attack and also against the elements.

10-3.1.4.2 Scheduling

A TOE field maintenance unit can do little formal scheduling of repairs. Most repairs are made on an on-call, as-needed basis. However, many TOE field maintenance units have endeavored to achieve some form of scheduling whenever possible. By judicious use of visits, regular work contact, and inspections, a field maintenance unit often can anticipate major repairs and do advance scheduling on certain types of items and repair jobs.

10-3.1.4.3 Inspection, Work Control, and Reporting

Operation of a mobile or semimobile TOE shop follows the basic pattern of fixed shops. Control over repairs is exercised in most cases by an operations section of a direct or general support unit or by the chief of each repair section within the unit.

The following typical inspection, work control, and reporting functions are performed by TOE shop personnel:

a. Inspection. Most field maintenance units have trained personnel specifically designated as inspectors who are attached to the operations section. They usually perform a thorough initial inspection of items brought into the shop area for repairs to determine the exact nature of the work and repair parts required. Deficiencies of organizational maintenance also are noted. The earlier on-site inspections usually are made by repairmen attached to mobile teams assisted, as necessary, by regular inspectors. In-process inspection may be made to insure quality or to identify areas needing improvement. Final inspections regularly are performed before a repaired item is returned to the user or to stock.

b. Work Control. The work flow is similar to that in fixed shops except for the physical differences. After inspection, a job order number usually is assigned and the job, with its accompanying work request and job order form, moves to the various vans or bays for necessary repairs. Control is exercised by the operations section, or its equivalent, monitoring the job progress and expediting the work. The necessary parts are obtained by the supply section and issued to the repair sections.

Most TOE shops keep a work flow board showing the location of various job orders with an expected date of completion. Repair section chiefs generally submit a daily report that lists job order progress and notes any unusual delinquencies in parts or tools that are delaying a job.

c. *Reporting.* To assist the field army in overall control over field maintenance, the TOE field shops report performance to higher headquarters on the maintenance readiness and field maintenance costs form and the maintenance readiness of representative critical equipment form. Field Army and commanders are concerned about keeping deadlined equipment at an absolute minimum. Excessive deadlines can impair combat readiness of a Field Army seriously. It is incumbent upon direct support unit commanders to insure expeditious work flow and to notify general support units promptly when backup support is required.

10-3.2 DEPOT MAINTENANCE WORK FLOW

The depot is the basic facility within the supply system for receipt, inspection, classification, storage, preservation and packaging, assembly, disassembly, maintenance, and issue of materiel. The minimum task of the depot supply function, simply stated, is to receive, store, and care for supplies while in storage, process applicable demands, and ship supplies against these demands within specified time frames. Army depots are the primary storage and distribution points for the Army wholesale supply system. Army depot missions are established by Headquarters, Department of Army, and the Commander, AMC. The statement of missions prepared for each depot contains the functions, scope, and purpose of the depot, including any limitations that may be placed on it. Depot missions generally are classified into three groups: stock distribution/storage, depot maintenance, and other.

Stock distribution/storage encompasses the functions of receipt, storage, preservation and packaging, and shipment of materiel as directed by the National Inventory Control Point commodity managers. In addition, Army depots may perform storage functions for materiel belonging to other services or agencies.

Depot maintenance augments stocks of serviceable materiel, and supports organizational, direct support, and general support maintenance activities. Depot maintenance includes the functions of inspection, test, repair, fabrication, modification, alteration, modernization, conversion, overhaul, reclamation, or rebuild of parts, components, subassemblies, assemblies, and end items.

In addition to the missions previously mentioned, Army depots have other missions to perform. Some of these missions are small arms ammunition clipping and linking, materiel demilitarization, ammunition and petroleum surveillance, and modification of equipment (Ref. 4).

10-3.2.1 Depot Production Planning and Control

The Production Planning and Control System is used for planning, accepting, scheduling, costing, and reporting organic depot maintenance workloads. Workload requirements are determined initially by the National Inventory Control Point and are issued by the central workloading activity—the United States Army Major Item Data Agency (Fig. 10-2). The Production Planning and Control System is applicable to AMC depots for:

a. Planning, programming, scheduling, and performing depot maintenance, modification, conversion, alteration, renovation, or fabrication of materiel authorized through the Major Item Data Agency

b. Planning, programming, and scheduling of depot maintenance support services.

10-3.2.1.1 Generation of Requirements

The Production Planning and Control System, to the maximum extent practicable, embodies the principle of management by exception. To achieve this principle, automatic data processing equipment is used extensively in program planning, acceptance, parts forecasting, scheduling, and analysis as part of the SPEEDEX (System Wide Project for Electronic Equipment at Depots, Extended) system.

In addition to current year workloads, depot maintenance activities receive 5-yr work projections in accordance with the Army 5-yr maintenance plan; i.e., current year, target year, target year plus 1, plus 2, plus 3, and plus 4. Current and target year work is scheduled and reported to the United States Army Major Item Data Agency as changes occur. Target year plus 1 through 4, as a minimum, is updated semiannually by the Major Item Data Agency.

Exchange of maintenance data between the Major Item Data Agency arid performing activities is through the use of automatic data processing equipment. The system provides for automatic followup on pending actions and establishes suspense dates for required inputs. Data contained in the Major Item Data Agency data bank are the official source for AMC in making management decisions. In this connection, management at the local level, to the maximum extent, controls their respective areas of responsibility through use of automatic data processing equipment generated reports from data contained or computed in local equipment. In cases where errors exist, corrective action is taken and verified by a subsequent automatic data processing equipment report. Management at the depot level, through use of standard automatic data processing equipment generated reports, minimizes the potential for unsound higher authority decisions based upon data contained in the Major Item Data Agency data bank.

Current year orders are processed as follows:

a. Work orders emanating from the Major Item Data Agency are input directly into automatic data processing equipment without intervention. In cases when data do not pass the local validation procedure, the order is returned to the Major Item Data Agency for resubmission. Orders that pass validation are processed automatically and accepted if within established parameters. A program notice is produced and directed to the responsible production controller. It should be noted that the program notice provides visibility to accepted orders, required schedules, priorities, program control number, item name, AMC procurement request order number, customer, work accomplishment code, and unit cost estimates, and is used for audit purposes. Each time a change occurs in the planned/authorized quantity or unit funded/total cost, a new program notice is produced.

b. Orders that are not within established parameters are directed to the responsible production controller for action. A suspense date

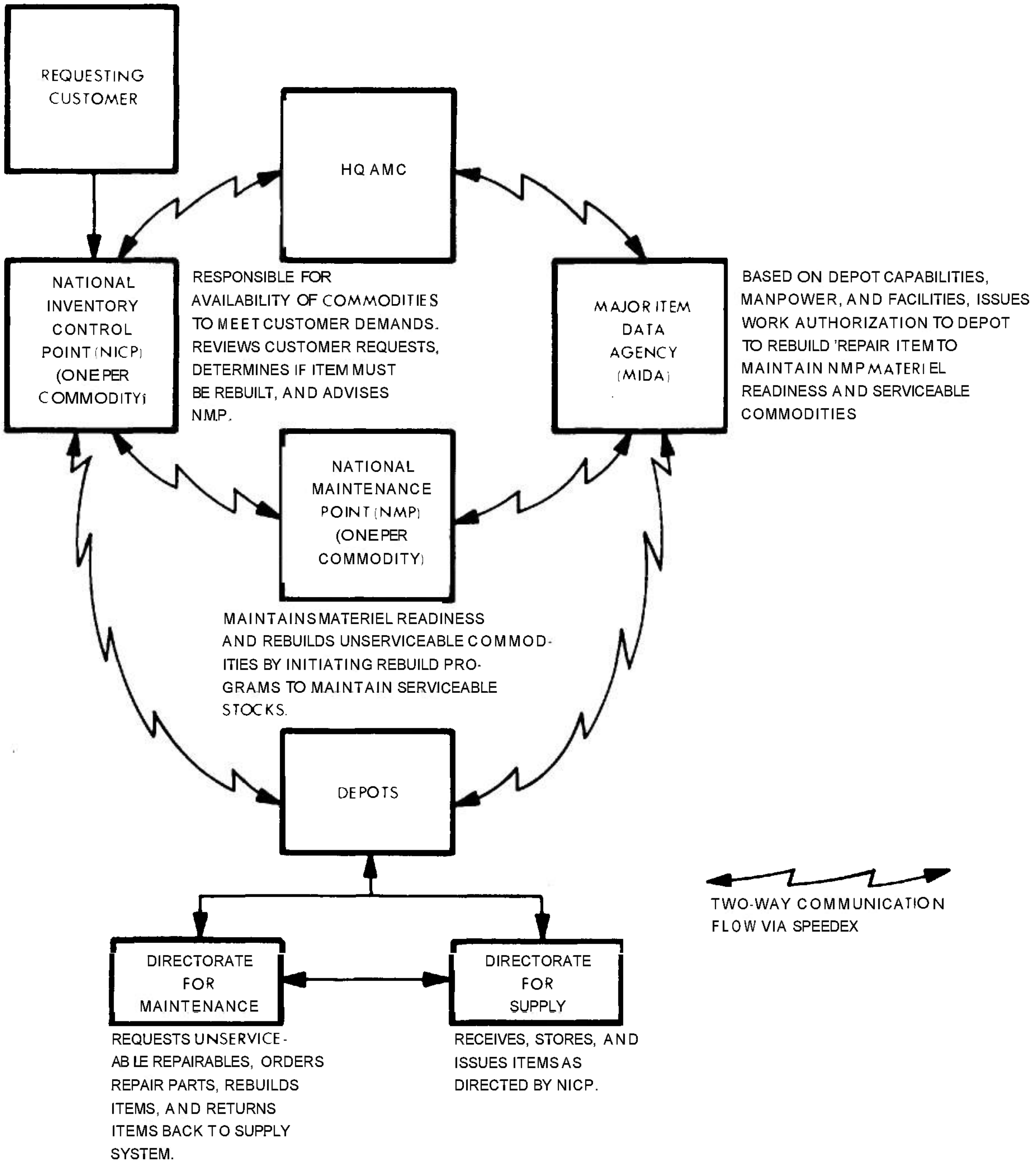


Figure 10-2. Generation of Depot Maintenance Requirements

is established for reply to the system. In cases when no action is taken on the part of the production controller, a followup program notice is produced. Data within the system that created the condition are retained in a negotiation file pending response by the maintenance production control activity. When input is received, the appropriate response is forwarded to the Major Item Data Agency.

Target year orders are processed in the same manner as current year orders. Monthly schedules and cost information are passed from and to the Major Item Data Agency as changes occur.

Orders for target years plus 1 through 4, as a minimum, are received by performing activities semiannually and are used for planning purposes.

Job order control for the current year is accomplished through use of machine-generated reports, or a remote inquiry system. Provision is made for automatic reports to draw attention to exception type of conditions. Job order costs are machine-monitored during execution, as costs are posted to the job order record. Reports are produced automatically whenever applied costs- indicate that a projected cost will be outside the billing price variance. Job orders that are projected to be over/under the billing price variance are placed in a suspense negotiation file automatically. Response by the responsible production controller is mandatory within 5 days if renegotiation is not desired.

Price adjustment to individual job orders is accomplished within the production control activity by updating direct labor man-hour requirements at work center unit production code levels, adjustment to part cost per unit, or adjustment of other costs per unit. Input to the system of the foregoing data causes a recomputation of the unit funded/unfunded cost and results in a renegotiation with the Major Item Data Agency. The record is held in suspense pending a reply from the Major Item Data Agency. Upon approval by the Major Item Data Agency of the revised unit funded cost, a program notice is produced reflecting the new authorized funds. The transfer of funds from one job order to another for the purpose of continuing a job in process during negotiation is not permitted. In addition, whenever an erroneous charge is posted to a record, the procedure that follows is adhered to:

a. Corrective cost transfers exceeding $1,000 are documented on a journal voucher before being entered into the accounting system. The journal voucher is approved by the director of maintenance and contains a detailed explanation of why the transfer is being made.

b. These vouchers are subject to review and final approval of the depot comptroller.

10-3.2.1.2 Emergency Requirements

If a desired emergency item has been accepted previously by the depot maintenance activity, the Major Item Data Agency, upon receipt of the emergency requirement, telephones the depot maintenance activity and requests the item(s) within prescribed time frames. If the item is programmed but not authorized, the Major Item Data Agency takes action to authorize the order within 24 hr.

If a desired emergency item has not been programmed previously, the Major Item Data Agency telephones the selected depot to place the order. Confirmation of the order is provided by card transmission within 24 hr.

If commodity commands cannot place emergency orders through the Major Item Data Agency, direct communication to depots is authorized.

Confirmation of emergency orders flows through the Major Item Data Agency the morning of the first workday following each occurrence.

10-3.2.2 Depot Funding (Ref. 5)

Army Materiel Command depots operate according to 'the Army industrial fund concept. This concept was adopted to help balance workloads, funds, and manpower. It provides a uniform management and accounting procedure for depots throughout the command, as well as a more flexible means of financing industrial and commercial operations.

Under the concept, payments are made from the Army industrial fund account for labor, materials, and services. Uncompleted programs may be carried over to the next fiscal year. The Army's Major Item Data Agency serves as a central data bank to determine the workload situation of each depot. It also acts as an agent of the customer in dealing with the depots, and reimburses the Army industrial fund from the customer's money, replenishing the revolving fund.

The National Inventory Control Points within the Army Materiel Command normally assume the role of the customer, contracting with the depots for services such as maintenance and repair, storage and transportation, or calibration. In other instances these depot service elements become the customers, and the depot support operations—depot equipment, facilities, or data operations, for example—are the servicing agents.

The Major Item Data Agency pays the bills from the customer's funds for operation and maintenance, minor military construction, family housing, or whatever customer accounts are applicable.

One advantage of the Army industrial fund concept is that competition between depots for work is increased, resulting in more stringent depot management. Depot commanders are held more responsible for keeping production rates high and overall costs reasonable. The system provides better management tools and calls for improved management as a result of their use.

10-3.2.3 Nature of the Depot Maintenance Shop labor Force (Ref. 1)

An inherent problem associated with depot labor forces is that of maintaining compatibility between the workload and the number of personnel. This problem is offset to some degree by the diverse skills that some depot personnel possess.

10-3.2.3.1 *Quantitative Inflexibility*

Unlike many industrial concerns, which are able to achieve flexibility in their labor force by hiring workers in periods of peak production output and laying them off when the volume of work declines, most Army depot maintenance shops have labor forces that are relatively inflexible. This condition is true for several reasons. Many depot maintenance shops in CONUS, for example, are located in isolated, nonindustrial areas. Often, the military and civilian personnel who work in these shops form a large percentage of the skilled work force in the area. Under such circumstances, if labor requirements at the maintenance shop increase, it often is difficult or impossible to hire additional trained workers. If, on the other hand, the workload at the maintenance shop decreases, and workers are laid off, the workers may move away from the area entirely—especially if there is insufficient commercial industrial activity available to absorb them. It is imperative, therefore, that available manpower in the maintenance shops be retained. Another reason why the depot maintenance shop work force is relatively inflexible is that the size of the labor force required to execute the program for a budget year usually is determined during the budgetary process and, in most instances, is conditioned by the best available estimates of the prospective workload of the shop. Estimates are based on historical records and, consequently, have a certain "built-in" inaccuracy. The labor ceiling prescribed in the budget seldom is exceeded in actual practice, not only because of restrictions imposed by directives but also because additional skilled personnel needed for an expanded overhaul operation are seldom available. Also, in all probability, additional skilled personnel who might be available would be unwilling to work on a temporary basis.

Civilians employed in depot maintenance activities usually are classified as either wage board or general schedule employees. As such, they have been trained, in many instances, in positions peculiar to a military specialty and, in some cases, the positions in which they work are found infrequently in private industry. The Federal Government, therefore, has a valid interest in the retention of such trained personnel, and every effort is made to balance workloads so as to avoid personnel fluctuations. Such efforts tend to provide a reasonable degree of job security and to insure the retention of a stable maintenance shop labor force. Government regulations controlling labor generally are no more restrictive than the job security provisions negotiated by industry and labor unions during collective bargaining.

When the maintenance workload exceeds shop capacity at a depot, several alternatives are available to the commander. The shop might go on an overtime status, personnel might be shifted from shops in other depot divisions, or a portion of the work might be contracted to commercial organizations. These alternatives have their limitations. For example, the use of overtime may be restricted by funding limitations; the technical nature of some overhaul operations may prevent the movement of employees among depot activities; and contract maintenance sources that are technically qualified for the work involved may be too costly or too far removed from the depot to be worthwhile. The problems created by a relatively inflexible labor force vary with the adequacy and accuracy of production programs and schedules generated at command levels. If the actual workload at a maintenance depot shop coincides closely with initial estimates and planned production schedules, production management will have relatively little difficulty in meeting labor requirements. If crash programs occur or initial production schedules bear little resemblance to the actual workload received, difficulties of the types discussed will arise.

A factor that helps to compensate for labor force inflexibility is the scheduling of annual leave. If employee leaves are scheduled during slack periods of maintenance activity rather than during peak periods, maximum use of the existing labor force can be achieved. In planning any production operation, the factor of unscheduled worker absence must be considered.

Army depots in oversea theaters are faced with the same problem of inflexibility of the labor force as are the depots in CONUS. Moreover, other problems confront the commanders of an Army depot overseas. In relatively undeveloped countries, unskilled labor may be plentiful, but skilled labor generally is scarce and most depot employees must be given extensive on-the-job training in production techniques. This training usually is hampered by a language barrier that is not overcome easily.

10-3.2.3.2 Skill flexibility

The adequacy of the maintenance facility, the type of materiel to be repaired or overhauled, and the form of production arrangement involved—bay shop, production line, or a combination of both—determine, to a great extent, the production skills required to perform the maintenance mission effectively. In a depot shop with a bay shop operation, workers normally are required to have more technical knowledge and mechanical skills than workers in a depot shop with a production line. The bay shop worker is not necessarily any less skilled at any one job than the production line worker. Usually, however, he must be able to do more than one job. Worker flexibility of this type helps to offset labor force inflexibility and enables the maintenance shop to support increased types and quantities of Army equipment. In general, depot maintenance operations require more highly skilled workers than do routine manufacturing operations.

Training personnel should be an integral aspect of depot shop operations. This requirement is necessary because of the following reasons: the depot, in all instances, cannot hire competent personnel who have the required skills; and multiple-skilled employees increase the overall efficiency of shop operations. Training for depot shop personnel may be conducted in formal off-the-job classes or by on-the-job instruction and supervision, with individual workers moved from time to time to work at different types of jobs. When new equipment is introduced, contract representatives and facilities may be used for training depot maintenance personnel. The primary responsibility for depot training rests with the depot commander.

10-3.2.4 Production Processes (Ref. 1)

Depot Maintenance Work Requirements (DMWR's) specify the depot maintenance processes required for an item of materiel. DMWR's prescribe the sequential steps involved in performing required maintenance from receipt and inspection through teardown, repair, assembly, and test, and conclude with preservation, packaging, packing, and marking instructions. Additionally, required tools, test equipment, repair parts, and maintenance times are specified.

An analysis of these data will reveal the most efficient type of production layout to accomplish the work called for in the DMWR. However, due to the varied demands that are placed on depots and the varied capabilities of depots, it is not possible always to use the ideal production layout for a particular DMWR.

A production layout may be described as the physical arrangement of facilities, equipment, special tools, and the necessary supplies for the purpose of repairing or overhauling equipment. Army maintenance installations commonly use the bay shop type layout or the production line layout. Each layout has its advantages and disadvantages. In general, the type of production arrangement or layout used at a particular maintenance installation depends on the following factors:

a. The magnitude of the maintenance shop workload as to the types and the density of items and equipment that are processed and the level of maintenance that is performed

b. The type of production facilities, such as machine tools, test equipment, and overhead cranes, necessary to perform the mission imposed

c. The size and nature of available production floorspace

d. The versatility and availability of the maintenance work force.

Production lines are used primarily for rebuild or overhaul operations involving a large number of high-density items. The bay shop technique is used primarily for operations involving low-density items or items which, regardless of density, are received by the depot for overhaul or rebuild in insufficient quantities to justify setting up a production line. A major exception to these general rules is electronic and communication equipment, which usually is overhauled or rebuilt in a bench-type layout without regard to the numbers of items involved. Bench-type layouts are merely a modified form of the fixed station or bay shop layout.

10-3.2.4.1 *Characteristics of a Production Layout*

Ideally, a production layout should be set up especially for the items to be overhauled. The building in which production is to take place should be large enough to contain the production layout. Such an arrangement, however, is not always possible at an Army maintenance facility. A depot maintenance shop is responsible for overhauling a variety of items and equipment, and a layout that is suitable for one type of equipment may be less suitable for another. Compromise solutions to layout requirements, thereby, become the rule rather than the exception. All layouts, however, require efficient planning and meaningful arrangement of in-plant facilities. Well-conceived layouts facilitate motion economy, reduce costs, speed up the production effort, keep material movement and backtracking between processes to a minimum, reduce material handling costs, and provide a sufficient amount of in-process storage space. Finally, a layout should be flexible enough to allow changes to be made in the production operation, as necessary to accommodate demands for changes in program requirements.

10-3.2.4.2 *Bay Shop or Fixed Station Layout*

A bay shop or fixed station method of operation dictates that the equipment to be repaired or overhauled remain in one shop location until the work has been completed. The personnel and special tools necessary to do the work are moved to the equipment. Under a modified bay shop operation, machines performing the same or similar jobs are grouped together in sections, and the equipment to be repaired moves from one section to another at irregular time intervals until the work has been completed. Bay shop layouts normally are used for depot overhaul only when there are not enough like unserviceable items or production resources to permit the establishment of a production line. The lower portion of Fig. **10-3** depicts a modified bay shop operation in which utility vehicles are being overhauled.

The principal advantages of the bay shop type of operation are its flexibility and adaptability to changing conditions and demands. Bay shop operations generally require a large number of portable handtools. The machine tools used are commonly the general-purpose variety—including overhead cranes and material handling equipment. Changeovers from one type of equipment to another may be made expeditiously because there are few, if any, complex setups to tear down or to assemble and no production line to clear before other work can begin. In a bay shop operation, workers tend to become more versatile and, therefore, more flexible, because they handle a variety of jobs rather than a single operation or a group of similar operations, as is the case on a production line. Workers having the required skills and training generally are in higher wage brackets than are production line workers—a factor that may contribute to higher operational costs.

10-3.2.4.3 *Production Line Layout*

A production line process permits like items to flow in a definite sequence through

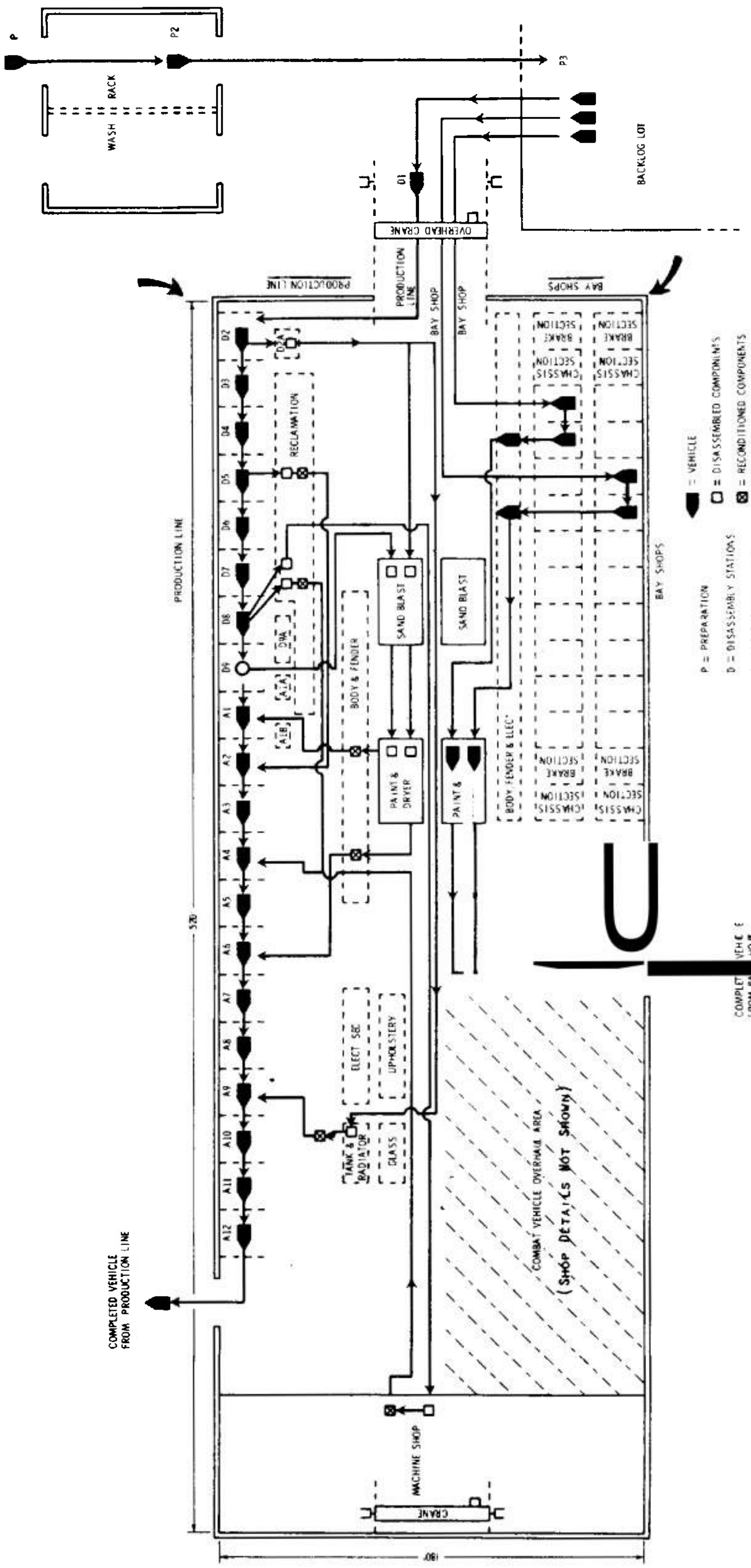


Figure 10-3. Bay and Production Line for Vehicle Overhaul (Ref. 1)

a number of designated overhaul stations. The production process begins with the disassembly of equipment, and it proceeds until complete reassembly has been accomplished. At each station on the production line, the same operation is performed on each item of equipment. The production line layout used in depot overhaul differs from the layout used for mass production line processes used in industry in that mechanical conveyor systems, which move in-process items at fixed and continuous rates of speed along the production line, seldom are used. This difference is necessary in a depot shop because of the flexibility needed when the overhaul program changes constantly from one type of unserviceable item or requirement to another. The top portion of Fig. **10-3** illustrates a production line operation in which utility vehicles are overhauled.

The chief advantage of the production line layout is the economy and efficien'cy with which large quantities of similar or identical unserviceable items can be overhauled or rebuilt. Operations on a production line are laid out carefully in advance of production. The repetitive nature of the work at each station tends to increase the efficiency of the assigned worker and, thereby, to decrease the time necessary for each unit to move through the station. Moreover, because workers specialize in one type of operation, less general mechanical and technical skill is required than in a bay shop operation. Accordingly, a lower skill requirement makes it easier to recruit and train new workers. A second advantage of the production line layout is that it facilitates the handling and control of work in process by eliminating backtracking. If the line functions properly, work flows evenly between stations, and scheduling of work to subsequent stations becomes an automatic process.

The chief disadvantage of the production line layout is its inflexibility. Setting up a line for overhaul is expensive. It generally requires more extensive facilities and machine tools than a bay shop, and detailed setups frequently are necessary. Setting up a complex line may take an extended period of time. Therefore, the quantity of unserviceable items to be rebuilt should be large enough to justify setup and tooling costs incident to production line operations. Although its production capabilities unquestionably are greater than is possible with a bay shop operation, the production line layout is adaptable only to long-range production scheduling—not short-range. Before production can begin, a detailed standing operating procedure must be drawn up, setting forth the exact sequence of operations and the per-unit time required for operations at each station. In addition, these detailed procedures assign the proper number of workers to each station so that approximately the same number of equipments can be processed at all stations within a given time period. The line itself then will be in balance with the planned production schedule.

J0-3.2.4.4 *Functions and Luyout* of *Support Activities*

To have an effective overhaul layout, planners must be certain that repair, reconditioning, and reclamation operations are performed at support sections or stations that are removed from the main production line or bay shop overhaul stations or areas. Each production mission requires varying degrees of support operations and different types of support facilities. Consideration as to the proper location of support operations and the varying trade skills involved in performing them enables the planners to coordinate varying demands from several sources, attain a required level of flexibility, and achieve economy in the overhaul operation.

Separation of support operations from disassembly and assembly operations is necessary to achieve production efficiency. Fig. **10-3** illustrates typical locations for vehicle overhaul operations such as reclamation, sandblasting, preparation and painting, body and fender repair, upholstery, electrical, glass, and tank and radiator support. Support sections either may be fixed or portable. Fixed support sections generally are set up to accommodate more than one line or bay shop operation. The workloads of these sections are balanced out with parts, components, and assemblies that are needed for current production. Fig. **10-4** depicts the layout of a typical fixed support activity for transmission overhaul. As in the case of a major end item overhaul line, the overhaul operations are performed at various stations or, as in Fig. **10-4,** at planned bench stations. Figs. 10-5 through 10-7 depict top-level depot work flows for missile system oriented items.

10-3.2.4.5 Final Maintenance Processing

The final steps of the maintenance flow are acceptance and verification. These functions are performed under the authority of the depot quality assurance division. For example, armored vehicles are subjected to operation on a varied terrain test track, including watertight integrity testing, and a guidance section is tested on identical acceptance tooling as that used at the manufacturing facility to demonstrate acceptability to the Government.

Following acceptance, the items are packed or prepared for storage and subsequently are returned to the depot supply division. The return to supply and reporting to the National Inventory Control Point conclude the maintenance cycle.

10-4 MAINTENANCE FACILITY REQUIREMENT IDENTIFICATION AND ACQUISITION

Maintenance facilities are an essential part of a materiel support subsystem. The paragraphs that follow describe how maintenance facility requirements are identified and how the facilities are acquired.

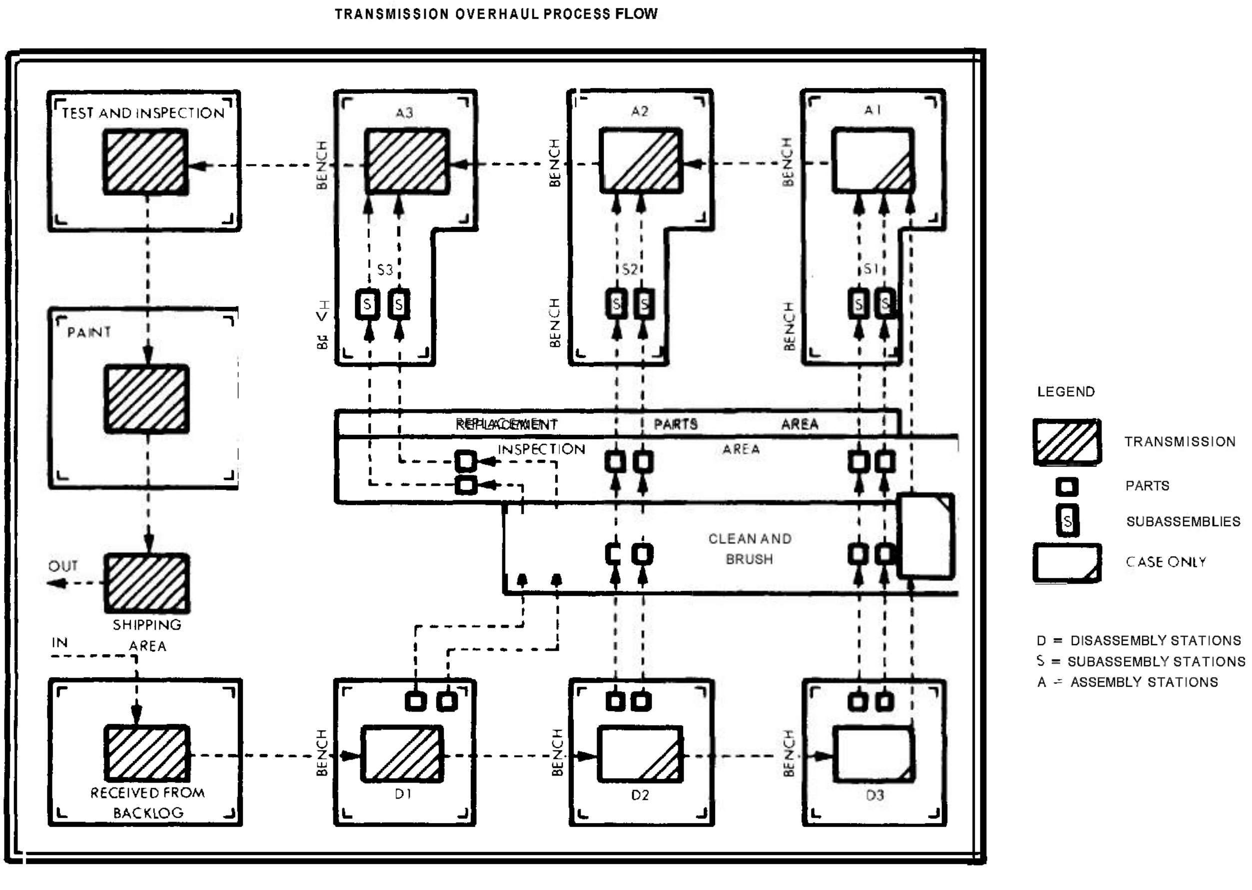


figure 10-4. Bench-type Support Operations (Ref. 1)

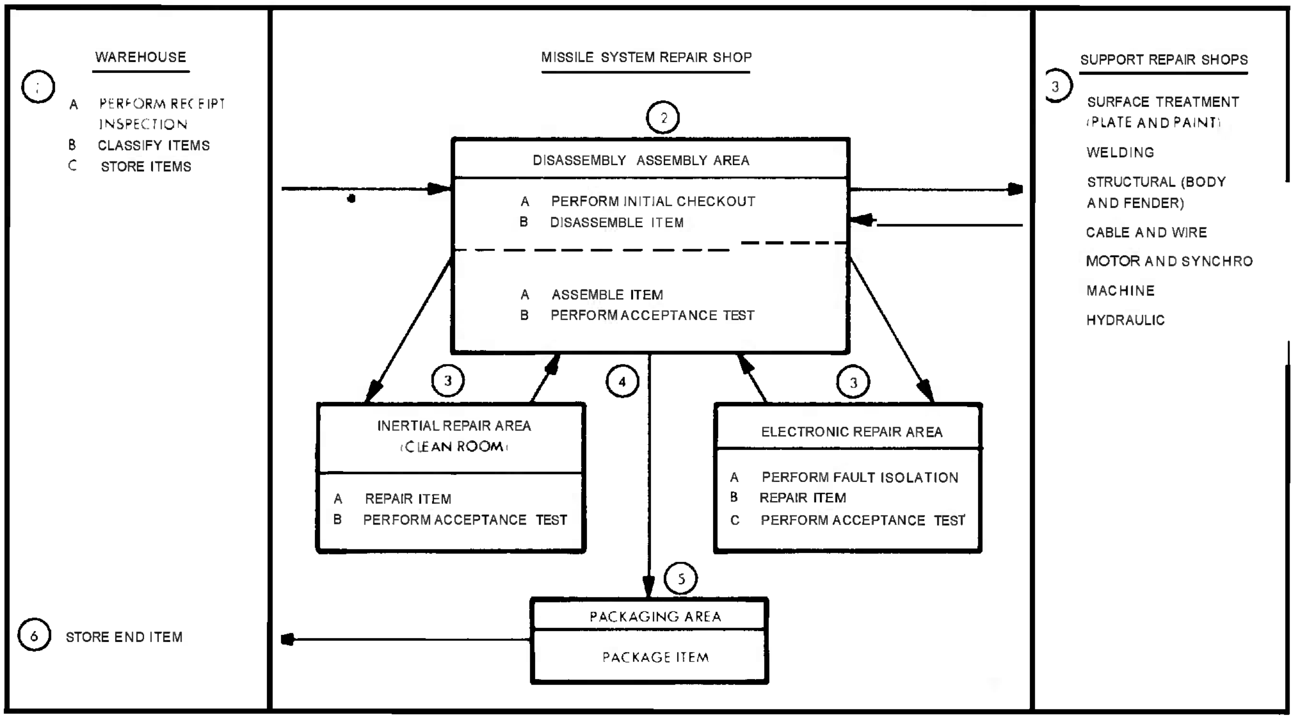


Figure 10-5. Major Operations of Nonexplosive End Items

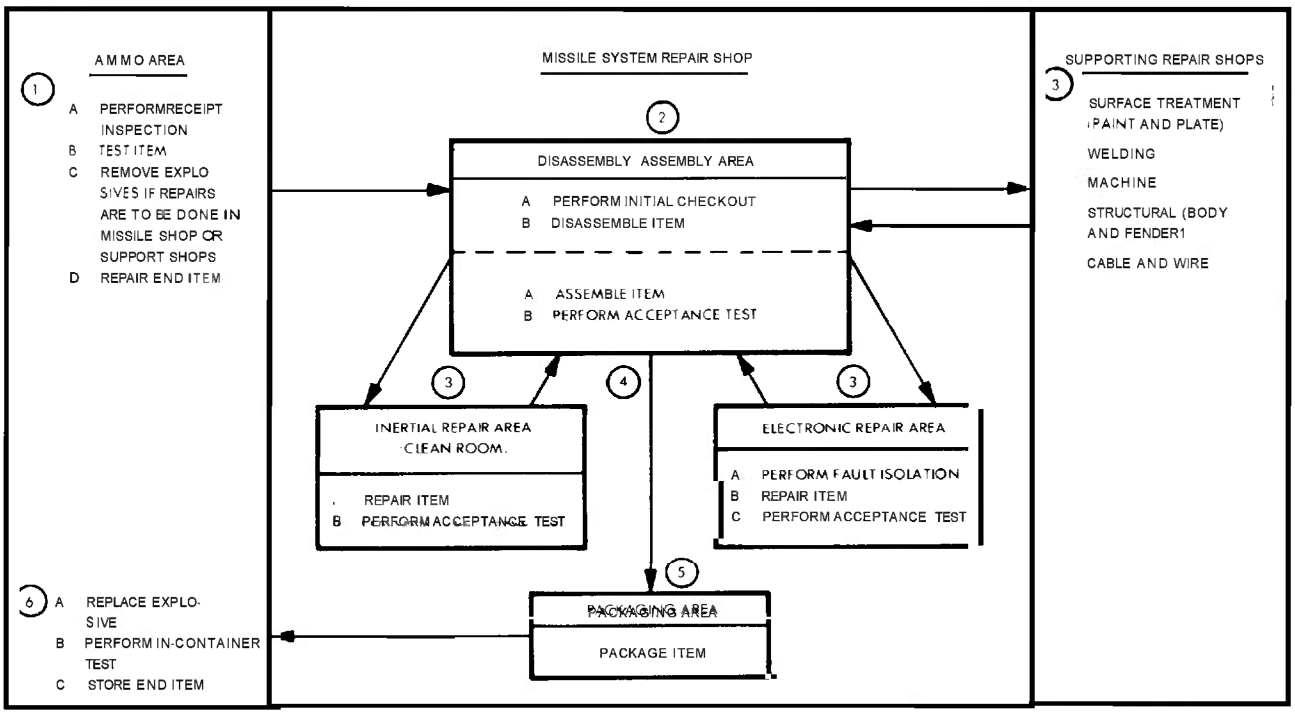


Figure 10-6. Major Operations of Explosive Classified End Items

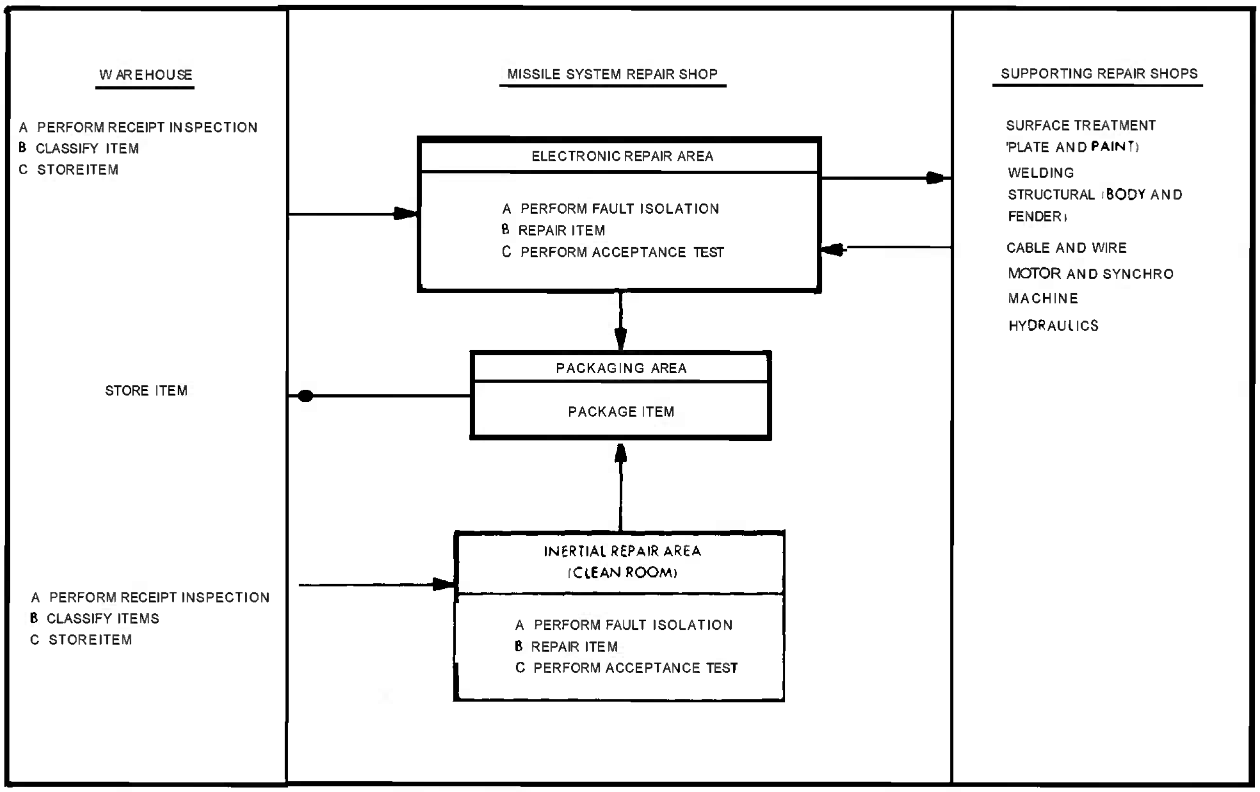


Figure 10-7. Major Operations of Secondary Items

10-4.1 REQUIREMENT IDENTIFICATION

The initial determination of materiel maintenance facility requirements is made by maintenance engineering during the conceptual phase. Due to the normal absence of detailed prime materiel design data, facility requirements at this time normally are relatively conceptual and are based, in large part, on historical data and judgment. However, these requirements permit the initiation of planning and programming that must occur if the facilities are to be available when required and provide life cycle costing information.

As the materiel progresses through the acquisition phase, maintenance engineering analyses provide increasingly detailed facility requirements. This refinement process is very important. Most systems generate some maintenance facility requirements that are unique (clean rooms, shielded rooms, isolated foundations, high bays, nonstandard door sizes, etc.). Maintenance engineering must define these and similar requirements in detail. It is not sufficient to state that a clean room is required; rather, the size of the room, sizes of the doors, airflow, permissible particle size, etc., must be specified.

It is of particular importance that all facility requirements be completely identified before a construction contract is negotiated. A subsequent contractual change normally has an adverse impact on both cost and the scheduled beneficial occupancy date.

Typical facility data that are developed through the maintenance engineering analysis process include:

a. Facility Requirements. These data provide a narrative description of the facility requirements based upon task descriptions, including the specified location and the quantity of facilities at each maintenance level.

b. Facility Design Criteria. These data include the requirements for items to be installed within the facility, turning space, clean room, ventilation, etc.

c. Facility Installation Lead ***Times.*** These data identify the lead times for contractors to produce and install support equipment.

d. Type of Construction. These data present information pertinent to any special construction, such as shock, hardness, and special floor loads, and construction type if different from the type normally provided.

e. Utility Requirements. These data provide a summary or estimate of the total connected load or gross quantity of utilities required, including hydraulic power and compressed gases.

f. Facility Utilization. These data provide the facility utilization rate.

g. Facility Unit Cost. These data reflect on the differences between the unit cost and military construction pricing guide costs that may exist due to unusual utility requirements or other special features.

h. Justification. This is a narrative that explains the requirement for new facilities.

i. Facility Sketch. This is a rough sketch that usually is prepared to show the tentative floor plan and facility layout.

10-4.2 FACILITY ACQUISITION (Ref. 8)

After facility requirements are identified, it is necessary to secure Military Construction, Army (MCA) funds and, subsequently, to build the facility. The steps normally involved in this process are:

a. At installation level, the functional proponent of the facility supplies the requirements to a facility engineer who transcribes them onto DD Form 1391.[1]

b. The Installation Commander convenes an annual Construction Requirement Review Committee (CRRC) that reviews MCA projects and establishes local priorities. The requirements are submitted to the next higher headquarters – for example, Hq. AMC.

c. AMC convenes a CRRC and establishes AMC installation priorities within funding limits established by the DA.

d. AMC and other major commands submit their projects to the Office of the Chief of Engineers.

e. The DA convenes a CRRC, chaired by the Assistant Chief of Engineers, and establishes Army installation priorities within funding limits established by the Office of the Secretary of Defense (OSD).

f. The fiscal year MCA Program is presented to the Army Budget Advisory Council. After acceptance, a joint OSD/Office of Management and Budget hearing is called to review the military construction program of each service. As a result of this hearing, OSD may delete or delay projects.

g. After the DoD Program is firm, each service provides Congress with copies of approved DD Forms 1391. Four House and Senate subcommittees hold hearings on the military construction program. These are the House and Senate Armed Services Subcommittees on Authorization and the House and Senate Armed Services Subcommittees on Appropriations. The program then is presented to the full Congress, where it is subject to further modification before passage into law.

h. MCA funds are appropriated to the Office of the Chief of Engineers, and are controlled by DD Form 1391 project numbers. Funds cannot be transferred between projects.

i. The District Engineer of the area in which the new facility is to be located manages the construction of the facility. He advertises for bids, awards contracts, provides an on-site resident engineer, disburses funds, etc.

j. The user is permitted to move into the building when the district engineer considers that it is ready for occupancy. Contractors are required to correct discrepancies before they receive final payment.

The time required to accomplish the activities outlined in the foregoing steps is significant. Under normal circumstances, 4 to 5 yr will transpire between the initial identification of a facility requirement and the beneficial occupancy date. This means that maintenance engineering must have reasonably firm facility re-

[1] **DD Form 1391 (Military Construction Project Data)**

quirements established several years before the initiation of production of a weapon system that requires the facility. This lead time is required for the facility review, appropriation, and apportionment cycle and for construction.

10-5 CAPITAL EQUIPMENT

Capital (plant) equipment is defined as property of a capital nature, consisting of equipment, furniture, vehicles, machine tools, test equipment, and accessory and ancillary items, but excluding special tooling and special test equipment, used or capable of use in the manufacture of supplies or for any administrative or general plant purpose (Ref. 6).

The Army Materiel Command performs capital equipment management in accordance with the maintenance plant equipment program. This program is designed to project future equipment requirements, validate equipment needs, and define processing channels for equipment acquisitions. The intent of the program is to provide one integrated, 5-yr, AMC-wide depot maintenance plant equipment program which will (Ref. 7):

a. Forecast valid maintenance plant equipment requirements

b. Provide details for financial budgeting

c. Support justification for equipment authorizations

d. Project future needs for programming equipment acquisition

e. Provide for advanced coordinated facility planning

f. Preclude unnecessary duplication of maintenance plant equipment

g. Establish modernization and standardization procedures and reporting requirements

h. Allocate available dollar resources according to AMC-wide priorities

i. Combine with the depot maintenance program, scheduling, workloading, and reporting system

j. Interface with the installation equipment management program and the Army authorization documentation system.

In the conceptual phase of materiel development, the definition of capital equipment to support new materiel usually is limited to a top-level analysis of the general requirements at all maintenance levels to ascertain the need for standard, new, or unique types of capital equipment resulting from the peculiarities of the design, materials, processes, etc. During the development phase, these requirements are defined further to facilitate the planning, scheduling, and procurement, if required, of these items. The plant equipment is identified in the depot maintenance data bank to provide the Director of Maintenance with total visibility of equipment projections. The integration of the total plant equipment program is depicted in Fig. 10-8.

USAMC DIRECTOR FOR MAINTENANCE
STAFF SUPERVISES DETERMINATION OF TECHNICAL REQUIREMENTS FOR MAINTENANCE FACILITIES TOOLS AND TEST EQUIPMENT COORDINATES AND MONITORS INDUSTRIAL ENGINEERING ACTIVITIES FOR MODERNIZATION AND STANDARDIZATION OF THE PHYSICAL ASPECTS WORLDWIDE DIRECTS THE DEPOT MAINTENANCE PROGRAM

USAMC MAINTENANCE MANAGEMENT CENTER
SERVES AS THE AGENT TO COORDINATE FOR APPROVAL THE USAMC PLANT EQUIPMENT PROGRAM DEVELOPS AND MONITORS MODERNIZATION AND STANDARDIZATION

ITEM MANAGER
COMMUNICATES PLANT EQUIPMENT PROGRAMS TO THE DEPOT MAINTENANCE DATA BANK IN COORDINATION WITH THE MAINTENANCE MANAGEMENT CENTER DETERMINES TECHNICAL REQUIREMENT

CENTRAL WORKLOADING ACTIVITY
SERVES AS THE AGENT FOR AUTHORIZATION FUNDING AND REPORTING OF PLANT EQUIPMENT PROGRAMS

DEPOT MAINTENANCE DATA BANK
MAINTAINS ESSENTIAL PLANT EQUIPMENT PROGRAM DATA TO PROVIDE THE FOREGOING PROPONENTS WITH TIMELY MANAGEMENT INFORMATION

Figure 10-8. Capital Equipment—Integration and Responsibilities

The USAMC Maintenance Management Center provides operational support to the Director for Maintenance, Headquarters, AMC, in the planning and execution of Army-wide depot materiel maintenance and the maintenance support services program. One function of the

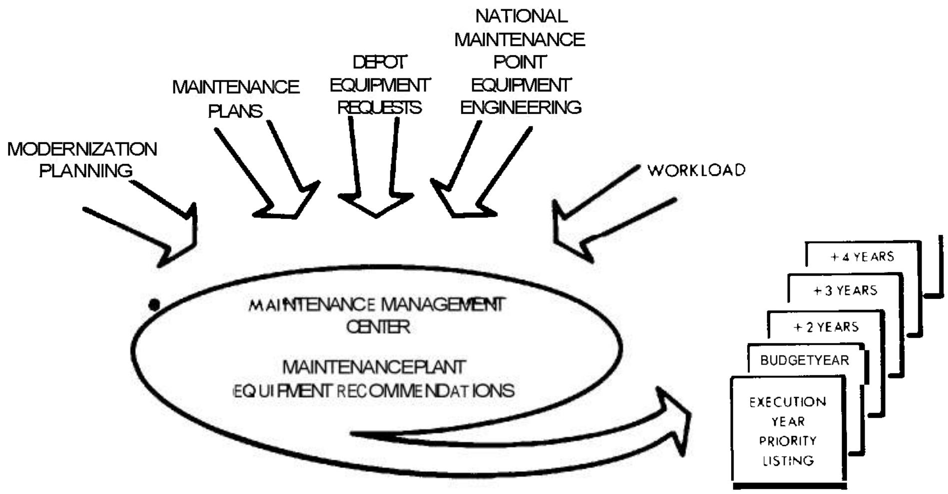


Figure 10-9. Capital Equipment—Identification, Recommendation, and Planning

center involves modernization and standardization of depot maintenance facilities, industrial plant equipment, and production methods and processes. The interface related to the maintenance capital equipment identification, recommendations, and planning is depicted in Fig. 10-9.

A brief description of how a depot-originated requirement for capital equipment becomes part of a continuing AMC 5-yr capital equipment program is described in the paragraphs that follow.

The request is forwarded to the Maintenance Management Center. The center determines that the item is classed properly as maintenance plant equipment, assures that justification is adequate, and determines the responsible activities or agencies that require coordination. Following preliminary coordination, the package is forwarded to the National Maintenance Point of the workloading commodity command for review and determination that the item is required to support the workload identified in the supporting documents. If the item/class manager is located at the workloading commodity command, action is taken by that command to send the requirement to the Major Item Data Agency. When the item/class manager is located at a supporting command, the request is documented by the National Maintenance Point and forwarded to the supporting command for class manager review and input to the Major Item Data Agency. When maintenance plant equipment requirements are originated by project managers, National Maintenance Points, etc., the same processing flow is followed for input to the Major Item Data Agency.

In all cases, the activity that originates a requirement for maintenance plant equipment forwards a copy to the Maintenance Management Center. Maintenance plant equipment requirements contained in the budget year and first out year require detailed justification which is adequate to substantiate funding and table of distribution and allowance authorization. The second through fourth out year requirements should be considered firm when entered, but do not require the detailed justification. As the second out year becomes the first out year, the Maintenance Management Center then will require adequate justification by the originator if the requirement is to remain in the program.

The 5-yr maintenance plant equipment program is reviewed by the Depot Maintenance Plant Equipment Management Council each year to provide a coordinated effort within the Army Materiel Command Maintenance Agency to approve the budget year requirements in detail and to obtain general approval of the out years. The results of this review permit the Maintenance Management Center to coordinate the approved plan with all interested activities and permit the Major Item Data Agency to cite funds, as required, during the execution year.

REFERENCES

1. FM 38-5, *Logistics Maintenance Management,* May 1969.
2. AR 750-1, *Army Materiel Maintenance Concepts and Policies,* May 1972.
3. DoD Inst. 4151.15, *Depot Maintenance Support Programming Policies,* 24 June 1969.
4. DA PAM 700-10, *Logistics Digest of Depot Operations Policies,* November 1973.
5. "Depots Use Industrial Funding", *Army Logistician,* May-June 1974.
6. **AR** 310-25, *Dzctionary* **of** *United States Army Terms (Short Title: AD),* June 1972.
7. AMCR 750-XX, *Depot Maintenance Plant Equipment Program (Draft),* 14 February 1972.
8. AR 415-15, *MCA Program Development,* 8 May 1969.
9. AR 310-49, *The Army Authorization Documents System (TAADS),* August 1972.

CHAPTER 11
MANAGEMENT AND CONTROL

This chapter discusses the basic steps of maintenance management as they apply to maintenance engineering activities, maintenance management control during system development, and maintenance engineering control of production maintenance. The maintenance management organizational interfaces between elements of the Office of the secretary of Defense and elements of the Department of the Army are addressed. The tools and techniques applicable to the management of maintenance engineering activities are described.

11-1 INTRODUCTION

Maintenance management is the function of providing policy guidance for maintenance activities, and of exercising technical and management control of maintenance programs. The overall maintenance management function includes the management of equipment maintenance, maintenance engineering, and maintenance production (Ref. 1).

Maintenance management of Army hardware begins at the highest national policy level of Government—the Executive Branch—where force structures and budgets are formulated. At the Department of Defense level, the Secretary of Defense is advised and assisted by the Assistant Secretary of Defense for Installations and Logistics. At this level, policies, directives, and regulations for maintenance form the basis for Army guidance within the overall Department of Defense logistic function. At the Department of the Army level, the Secretary of the Army exercises direction and control of materiel management and maintenance through the Assistant Secretary of the Army for Installations and Logistics whose office is concerned directly with Army maintenance. This office, in conjunction with the Deputy Chief of Staff, Logistics, is responsible primarily for overall Army maintenance management. It is at this level that the specific concept of management and' specific control of Army materiel originate.

The Army Maintenance Management System (TAMMS) is responsive to the needs of both field commanders and national level management requirements. It is a standardized and yet dynamic system. Standardization is necessary in the interests of the accuracy and efficiency that result from a common understanding of management goals and principles, which, fortunately, change very slowly. Dynamicism is necessary to meet constantly changing, detailed materiel support requirements that change with relative rapidity. Table 11-1 shows basic maintenance management functions that are performed by the Department of the Army and subordinate Army organizations that are engaged in maintenance management and/or maintenance operations.

TAMMS includes provisions for automated forecasting, distribution, scheduling, and production control of maintenance workloads commensurate with requirements and resources of major Army commands. It also features collection of necessary data to determine materiel maintenance costs in a way that permits extension of the basic concepts and principles of cost accounting and production reporting to maintenance facilities below the depot level. Also, provisions are made for maintaining visibility of the progress and costs associated with modification programs applicable to weapon systems and major end items.

Equally important, the system provides for the collection of equipment performance and maintenance performance data on primary (i.e., mission essential) weapon systems and end items to facilitate:

a. Developing failure patterns and repair factors

b. Monitoring the materiel readiness conditions of organizations and commands

c. Forecasting requirements for materiel and maintenance resources

d. Assessing the efficiency and effectiveness of maintenance operations.

In conjunction with data collection, standard forms and formats are prescribed for the collection, transmission, and display of information needed in the management of materiel maintenance.

TABLE 11-1. MAINTENANCE MANAGEMENT FUNCTIONS (Ref. 2)

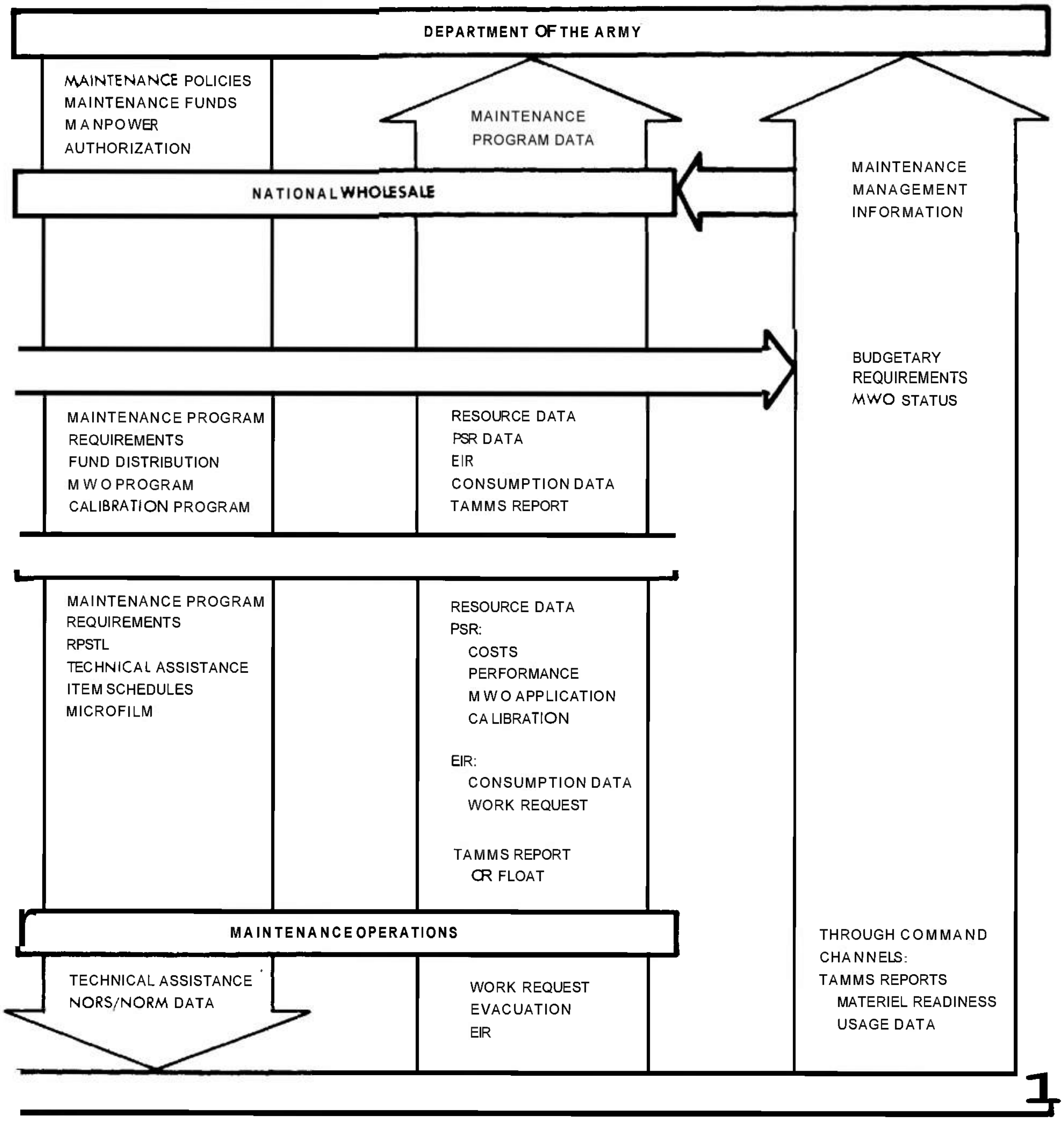
Management and Maintenance Levels	Functions								
	Directives	Policies	Command Policy	Technical Guidance	Program Planning	Program Operations	Program Control	Program Reporting	Program Analysis
Department of the Army	X	X							X
Major Army command/ USAMC			X	X	X			X	X
Subordinate command					X		X	X	X
Depot					X	X	X	X	X
General support					X	X	X	X	X
Intermediate support					X	X	X	X	X
Direct support					X	X	X	X	X
Organizational					X	X	X	X	X

TAMMS is oriented toward and emphasizes weapons and equipment as systems as opposed to commodity groupings of homogeneous items. It is developed on a modular basis to permit accommodation to various force structures and allocations of functions, and is designed to eliminate duplicative requirements for data collection. Further, it makes maximum use, especially at the higher management levels, of computer plotting techniques to produce simplified display type outputs that immediately pinpoint problem areas requiring management attention. The system uses exception reporting to the maximum extent practical, with periodic or summary reports held to the minimum, and provides data to determine or contribute to the determination of the effectiveness of integrated logistic support planning with regard to the performance of new materiel after it enters the operational inventory.

Data are an essential ingredient of any management system. Fig. 11-1 shows the several maintenance management levels and the flow of data among them. Essential data are provided to the Department of the Army for validation of maintenance policies, program requirements, standards, and priorities; measurement of the operational readiness status of Army materiel; assessment of the maintainability and reliability of weapon systems and equipment end items; and evaluation of maintenance resource expenditures and the effectiveness of the maintenance function (Ref. 2).

The other management levels include national wholesale management, maintenance program management, maintenance program operations management, and maintenance operations. A brief description of the management functions follows (Ref. 2):

a. National wholesale management. Concerned primarily with the validation, assessment, and measurement of the effectiveness of maintenance engineering and support and the



EIR — EQUIPMENT IMPROVEMENT RECOMMENDATION
MWO — MODIFICATION WORK ORDER
NORM — NOT OPERATIONALLY READY, MAINTENANCE
NORS — NOT OPERATIONALLY READY, SUPPLY
OR — OPERATIONAL READINESS
PSR — PROGRAM STATUS REPORT
RPSTL — REPAIR PART AND SPECIAL TOOL LIST
TAMMS — THE ARMY MAINTENANCE MANAGEMENT SYSTEM

Figure 11-1. Maintenance Management Data Flow (Ref. 2) control of life cycle management, product improvement, and configuration control.

b. Maintenance program management. Concerned with developing command maintenance programs, providing policy direction, determining resource requirements, suballocating funds, and assessing maintenance accomplishment in terms of materiel readiness and costs through a command reporting program and analysis of reports. This function generally is performed at the major Army command level.

c. Maintenance program operations management. Concerned with production planning of maintenance requirements and the control of workload and performance in maintenance activities within the command. It is that function of management which provides detailed program guidance and direction to operating elements and maintains control over workload, accomplishment, expenditure of resources, and reporting requirements. This function of management is performed by activities of organizations assigned by the major Army commander.

d. Maintenance operations. Responsible for the day-to-day accomplishment of maintenance in compliance with program direction and guidance received from maintenance program operations management functions. Maintenance operations include all categories of maintenance. Program status reports originating at this level reflect performance and costs applicable to weapon systems and equipment end items.

As illustrated in Fig. 11-1, information flows from the Department of the Army, through successive maintenance management levels, to the equipment owner (user), and from the user back to the top. Additionally, there is a separate channel for the user to report materiel readiness and usage data. This data flow provides an efficient and orderly method by which each management level can extract and insert appropriate information into a closed-loop system.

Materiel provided to the Army is becoming increasingly more complex. This is due primarily to technological advances and scientific breakthroughs of our modern industrial complex. Problems relative to managing and controlling maintenance of the sophisticated equipment have increased in direct proportion to the increase in complexity. Maintenance engineering management can play a significant role in controlling support costs and enhancing equipment operational readiness, since the inputs from maintenance engineering analyses define or limit many of the support parametars in the form of standards and requirements.

Maintenance engineering analysis is the single analytical logistic effort within the system engineering process and. is iterative throughout the acquisition program. Key inputs to this process, early in program phases, can have considerable influence on design and, hence, support characteristics of the emerging hardware design.

11-2 BASIC STEPS OF MAINTENANCE MANAGEMENT

The key to effective maintenance engineering activities is the application of a systematic and orderly management process to achieve:

a. Earlier consideration of support requirements in design and development of new materiel

b. Improved maintenance support and reduced skill requirements

c. Improved correlation, traceability, and integration of data elements related to support

d. Better definition and expression of work requirements associated with planning and development of support, and more timely and adequate support available for materiel during tests and at time of initial issue.

There are several basic steps involved in the maintenance management process that specifically aid in achieving the foregoing maintenance engineering objectives. These steps are delineated in Fig. 11-2 and described in the subparagraphs that follow. The steps are iterative, and many are performed concurrently. Therefore, no significance should be attached to the sequence of the depicted activities.

11-2.1 ESTABLISH AND IMPLEMENT MAINTENANCE POLICIES (Ref. 3)

The first step in the maintenance management process is the establishment and implementation of maintenance policies.

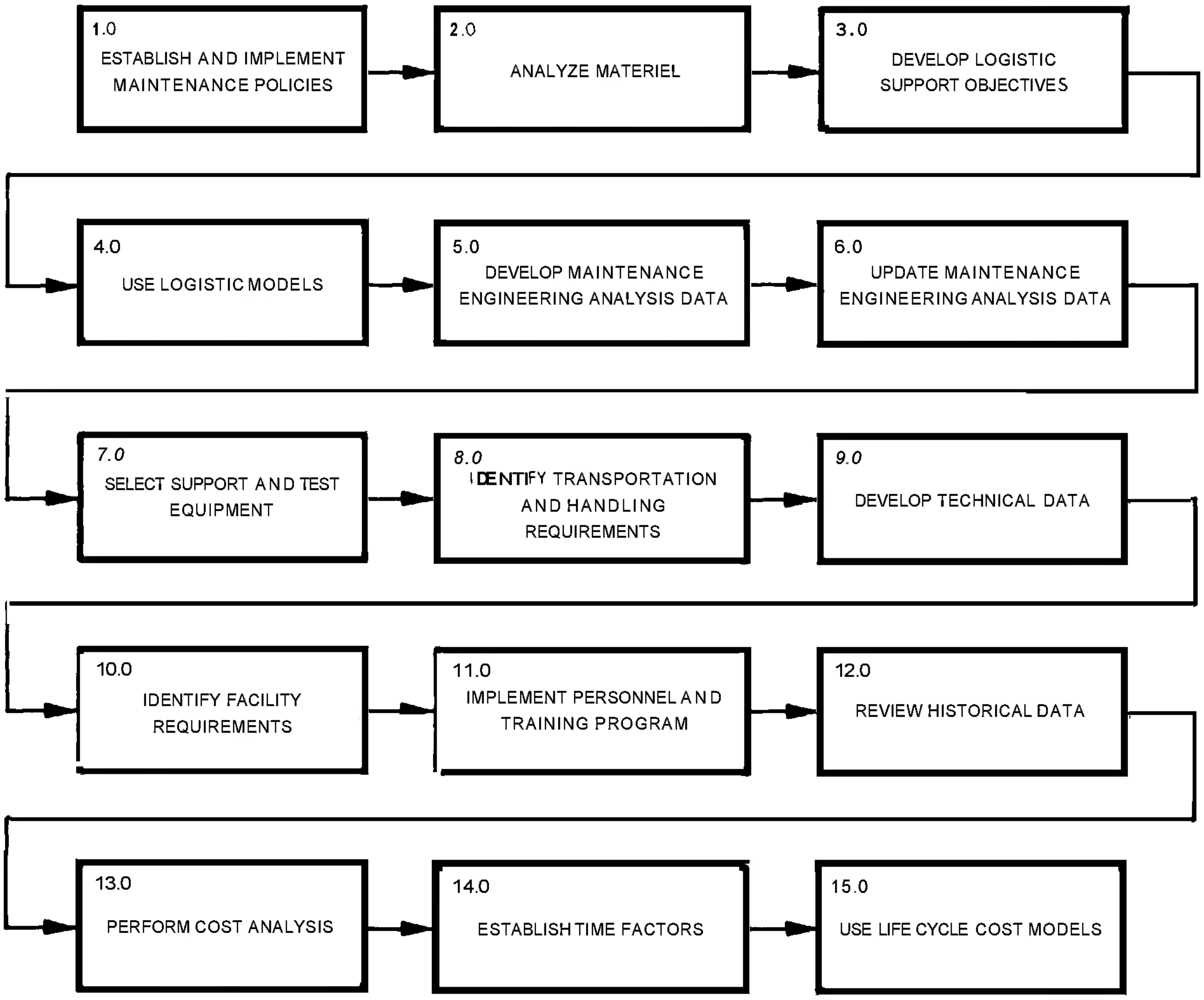


Figure 11-2. Basic Steps of Maintenance Management in Relation to Maintenance Engineering

11-2.1.1 Policy Establishment

The Army maintenance policies are derived from and are in consonance with decisions made at the highest levels of Government. The President, as the Chief Executive of the United States and Commander in Chief of the Armed Forces, is the focal point of the Federal Government organization. As such, the President is responsible for directing the affairs of the Executive Branch of the Government and executing the laws enacted by Congress. Decisions made by the President concerning force levels, weapon systems, oversea deployments, budget ceilings, and similar policy matters ultimately affect the extent and the nature of Army maintenance support required over any given period.

The National Security Council assists the President of the United States in determining national security policies. The President is Chairman of the Council. Other members are the Vice President, the Secretary of State, the Secretary of Defense, and the Director of the Office of Emergency Planning. The Council assesses and appraises objectives, commitments, and risks of the United States in relation to the actual and potential military power and considerations of national security. National Security Council policy decisions ultimately affect the amount and nature of Army maintenance support required for any given period. Fig. 11-3 shows the policy-making organizational levels between the President and elements of the Department of the Army.

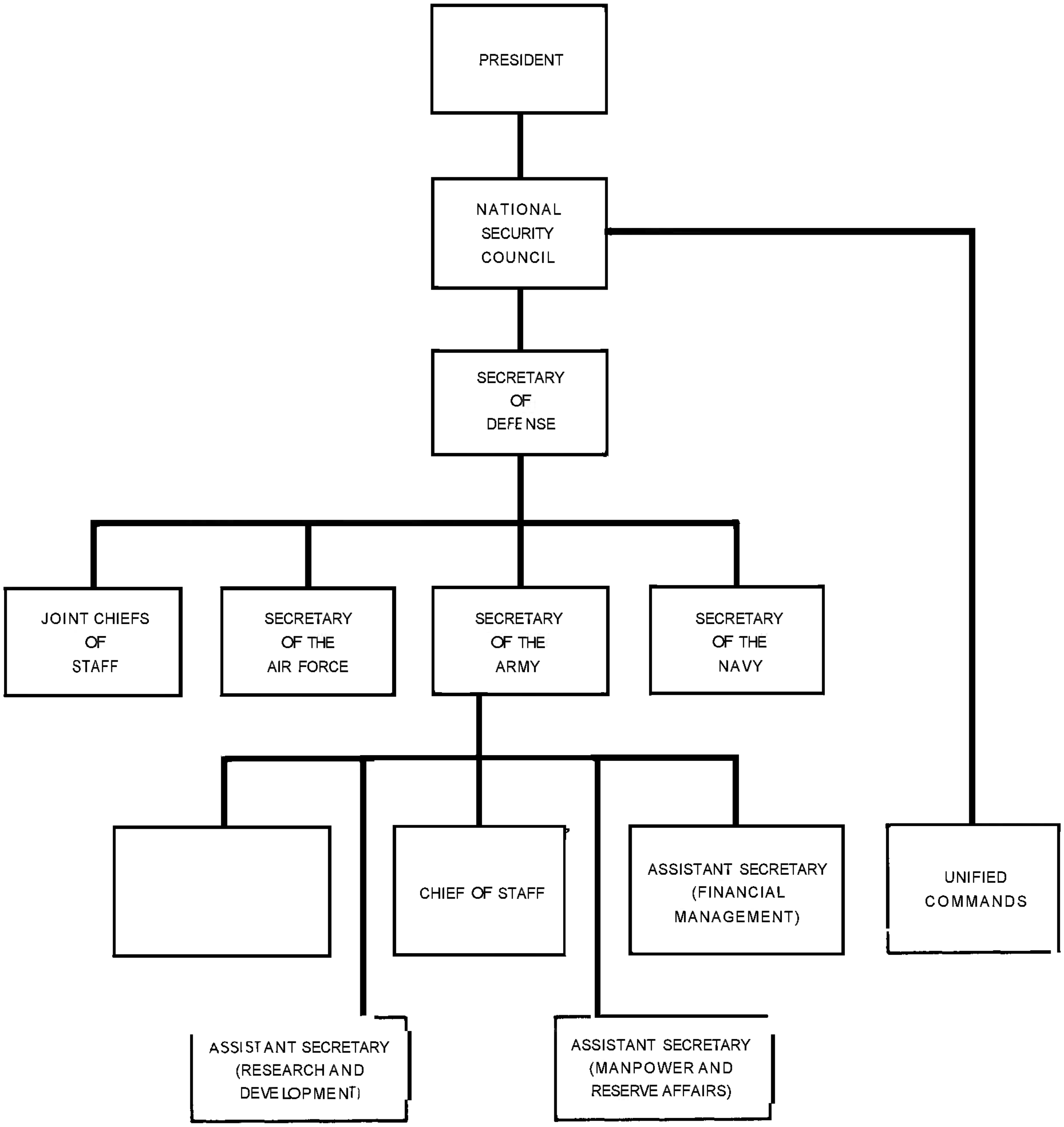


Figure 11-3. Organizational Relationship for the Army Maintenance Function (Ref. 3)

The Congress provides both the statutory framework within which the Army logistic system must function and the appropriations necessary for its operation. Hearings held by congressional committees often address maintenance management issues such as overhaul backlogs, industrial funding of depots and maintenance shops, and procurement of repair parts. Congressional hearings may lead to revisions of appropriations included in the Presidential budget or to legislation affecting the operations of the Defense establishment.

The Bureau of the Budget assists the President in preparing the budget and formulating the fiscal program. In addition, this agency supervises the administration of the budget, and keeps the President informed of the progress of funding actions. The Bureau also recommends adjustments to the proposed budget and to fund allotments to executive agencies after appropriations have been passed by the Congress. Funds included in the review performed by the Bureau of the Budget are the Army Appropriation (Operation and Maintenance) Fund, the Army Stock Fund, and the Army Industrial Fund. Together, these and others form the financial base for Army maintenance operations that implement long-range service maintenance policies.

11-2.1.2 Policy Implementation (Ref. 3)

Once long-range service maintenance policies have been established at the executive level, they must be implemented by the Department of Defense. The Department of Defense includes the Office of the Secretary of Defense and the Joint Chiefs of Staff, the several military departments and the military services within those departments, the unified and specified commands, and such other agencies as the Secretary of Defense establishes to meet specific requirements. Fig. 11-4 depicts the composition of this department. The Secretary of Defense exercises direction and control over Army logistic policies, including maintenance and maintenance management, through the Assistant Secretary of Defense for Installations and Logistics. The latter, in turn, is advised and assisted, specifically in the maintenance area, by the Deputy Assistant Secretary for Supply Maintenance and Services. Departmental policies and directives emanating from the Office of the Assistant Secretary of Defense for Installations and Logistics establish the basis for Army policies, directives, and regulations for maintenance within the overall logistic function. In addition, the Office of the Assistant Secretary of Defense for Installations and Logistics is responsible for the general monitorship of maintenance planning and programming, and the surveillance of maintenance systems and system performances.

The Assistant Secretary of Defense (Comptroller) supervises the preparation of the Department of Defense program and budget estimates and the preparation of proposed operating programs. As principal adviser to the Secretary of Defense in budgeting and fiscal matters, he recommends policies and procedures involving accounting, auditing, statistical reporting, and the use of working capital funds within the Department of Defense complex.

The Director of Defense for Research and Engineering is the adviser to the Secretary of Defense on scientific and technical matters; basic and applied research; development, test, and evaluation of weapons, weapon systems, and defense materiel; and design and engineering for determining item suitability, producibility, reliability, maintainability, and materiel conservation. He supervises all research and engineering in the Department of Defense.

The Joint Chiefs of Staff are the principal military advisers to the Secretary of Defense and to the President. The Joint Chiefs of Staff exercise strategic and operational direction of the unified commands and as such are responsible for the preparation of strategic plans for directing the military forces. Joint logistic plans are prepared by the Joint Staff of the Joint Chiefs of Staff, and logistic responsibilities are assigned to the military departments in accordance with approved plans. These plans form the basis of the Army plans for force levels, materiel, and facilities. In this manner, the actions of the Joint Chiefs of Staff influence Army maihtenance planning.

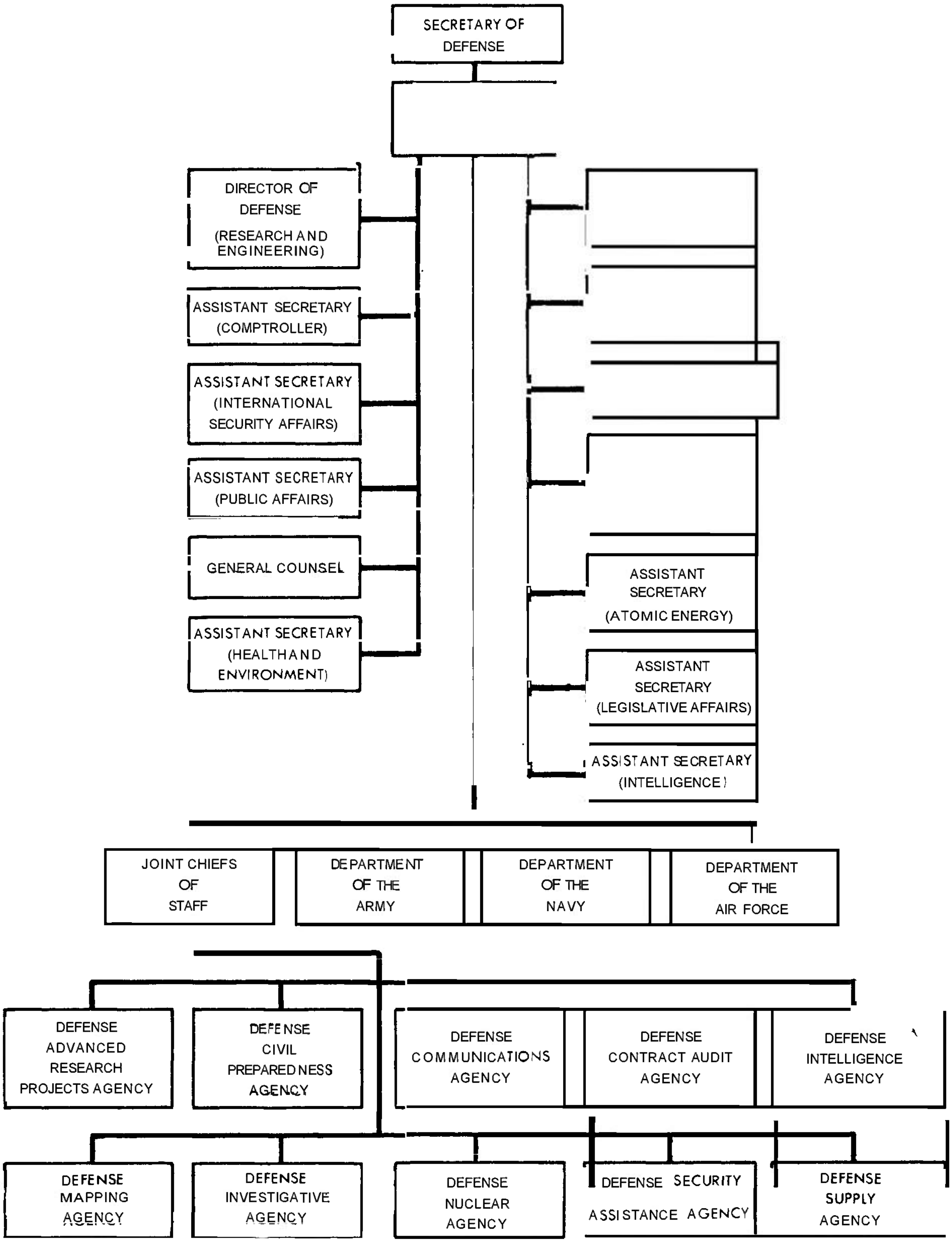


Figure 11-4. Department of Defense Organization Chart (Ref. 3)

The Army's organization for maintenance management is depicted in Fig. 11-5. The Department of the Army includes the Office of the Secretary of the Army, the Army General Staff, the Reserve Components, and all major Army field commands, installations, activities, and functions under the control or supervision of the Secretary of the Army.

The Secretary of the Army is responsible for all functions necessary or appropriate for training, operation, administration, logistic support and maintenance, welfare, preparedness, and effectiveness of the Army, including research and development. The Secretary of the Army exercises direction and control of materiel management and maintenance through the Assistant Secretary of the Army for Installations and Logistics. This latter official is concerned directly with Army maintenance. However, he does not exercise direct command over installation and logistic operations. His primary responsibilities are to supervise matters pertaining to the formulation, execution, and review of policies, plans, and programs in the installation and logistic area. The Secretary of the Army further is counseled and supported by the Assistant Secretary of the Army (Financial Management) and the Assistant Secretary of the Army (Research, Development, and Acquisition) in matters pertaining to their respective areas.

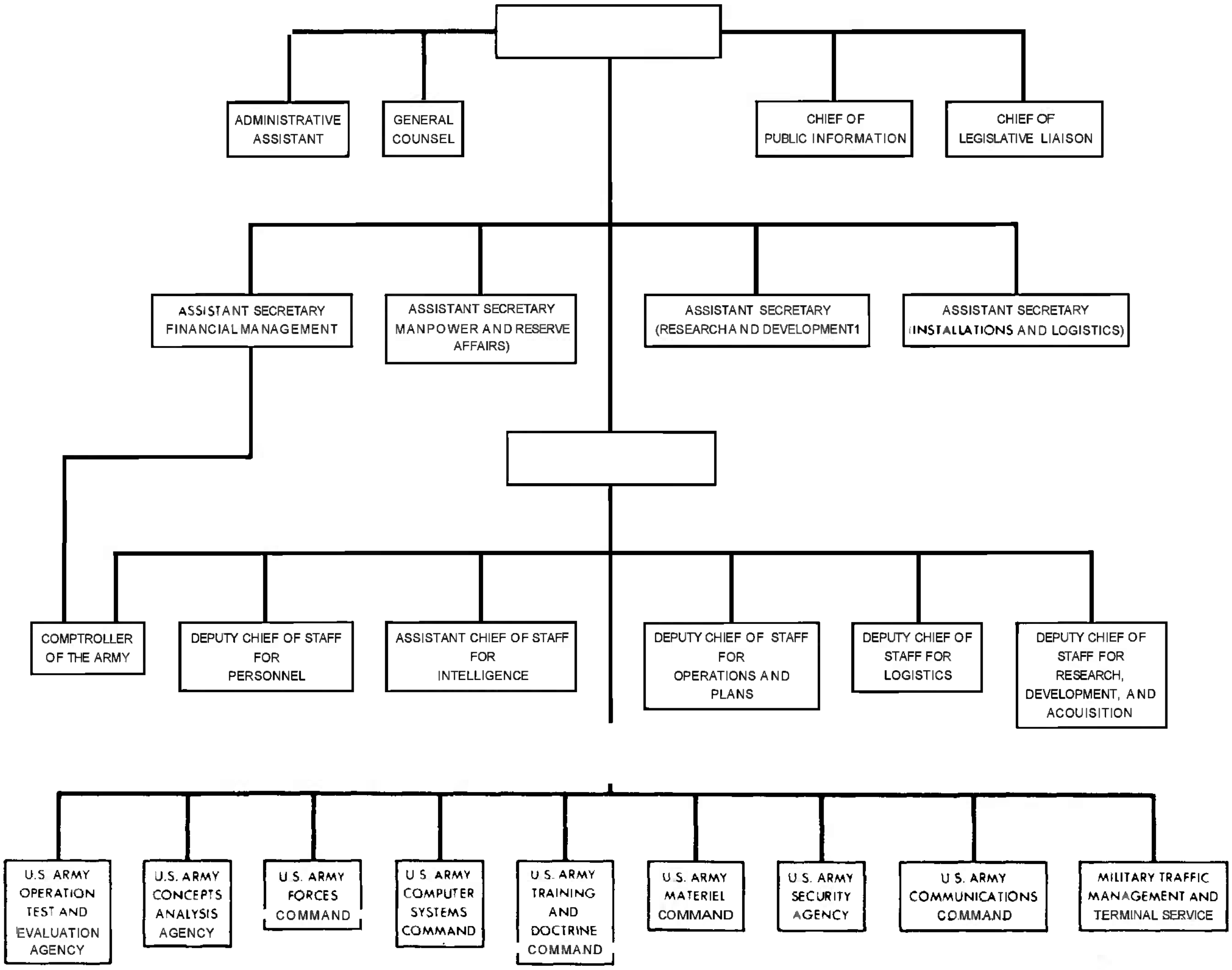


Figure 11-5. Organization of the Department of the Army (Ref. 3)

Under direction of the Chief of Staff, the Army General Staff advises and assists the Secretary of the Army, the Under Secretary of the Army, and the Assistant Secretaries of the Army in developing and promulgating broad basic policies for the Department of the Army. The Army General Staff also assists the Chief of Staff in preparing and issuing directives and programs to implement his plans and policies. In addition, the General Staff supervises the implementation and execution of these directives and programs.

The key organizational element within the Army associated with maintenance management is the Office, Deputy Chief of Staff for Logistics. The Deputy Chief of Staff for Logistics formulates and executes Army logistic policies. The Chief of Staff has assigned to the Deputy Chief of Staff for Logistics general staff responsibility for the management of all Department of the Army logistic activities. Specifically, the Deputy Chief for Logistics is responsible for:

a. Developing and supervising the Army logistic organization and system, including policies, doctrine, and standards

b. Performing logistic planning in support of United States and allied Army forces included in combined, joint, or Army operational and strategic plans, to include the logistic aspects of worldwide operational readiness of United States forces and materiel and the logistic position on Department of the Army force structures and force objectives

c. Managing materiel and supplies—including the determination of requirements—and devising plans, policies, and programs for the support of materiel systems from the completion of production validation through the disposal of the item

d. Planning and programming procurement and production requirements in the materiel acquisition process, and performing required surveillance during the procurement, production, delivery, and disposal phases of materiel life cycle management

e. Approving logistic plans, policies, and programs for military construction, family housing, real property management, and operation and maintenance of Army facilities, worldwide

f. Accomplishing the management analyses required for stock funding, industrial funding, and inventory accounting systems for logistic management purposes

g. Supervising the Army logistic support operations of activities involved in international logistics, to include military sales, grant aid, and cooperative logistic programs

h. Supervising the Army interservice supply operations

i. Supervising assigned logistic areas of the Army portion of the 5-yr defense program, corresponding areas in mobilization program documents, and installation stationing planning

j. Formulating, justifying, and supervising those portions of Army programs and budgets which pertain to the maintenance logistic area, within the overall guidance and policy developed by the Office, Assistant Vice Chief of Staff, and the functional guidance and policy developed by the Comptroller of the Army.

Table 11-2 summarizes the key organizational proponents for maintenance actions at the national, Department of Defense, and Army levels.

11-2.2 ANALYZE MATERIEL

A vital step in the maintenance management process is to identify the principal support/design interactions associated with a hardware program. Interactions between logistic support and design engineering activities are many, varied, and continuing—particularly in the early phases of a materiel acquisition program. Logistic feasibility studies should be made concurrently and should be correlated closely with technical feasibility studies. A continuous dialogue should be maintained between maintenance engineering and design engineering elements as an inherent part of system development. This relationship maximizes possibilities for early identification of problems, thus forcing design versus support trade-off decisions before the design is finalized. Maintenance engineering efforts during the early phases of the acquisition program are of special importance. During this period, materiel design and support design can be optimized with minimum cost and schedule impact. This is shown in Fig. 11-6.

TABLE 11-2. ORGANIZATIONAL PROPONENTS FOR MAINTENANCE ACTIONS (Ref. 3)

Maintenance Actions	Responsible Proponents
Develop national security policies	President; National Security Council; Department of Defense
Appropriations	Congress
Apportionments	Bureau of the Budget
Budgeting and financial management matters	Assistant Secretary of Defense (Comptroller); Assistant Secretary of the Army (Financial Management); HQ DA (Comptroller)
Logistic and maintenance policies	Assistant Secretary of Defense (I&L); Assistant Secretary of the Army (I&L); HQ DA (DCS for Logistics)
Materiel development (Army)	Assistant Secretary of the Army (R&D); HQ DA (DCS for Research, Development, and Acquisition, DCS for Operations and Plans, DCS for Logistics, and DCS for Personnel); U.S. Army Materiel Command; U.S. Army Communications Command
Personnel training and assignment	HQ DA (DCS for Personnel, DCS for Research, Development, and Acquisition, and DCS for Operations and Plans); U.S. Army Materiel Command; U.S. Army Training and Doctrine Command
General staff responsibility for materiel maintenance	HQ DA (DCS for Logistics)
CONUS wholesale maintenance activities	HQ USAMC; USA Communications Command; U.S. Army Security Agency
Worldwide depot maintenance program	HQ USAMC; U.S. Army Communications Command; U.S. Army Security Agency (for items under their cognizance)
Oversea depot maintenance operations	Army Component Commands of Unified Commands
Direct support, intermediate support, and general support operations	CONUS Army Commanders; Communications Command; Installation Commanders; Army Component Commands of Unified Commands
Organizational maintenance	Unit commanders

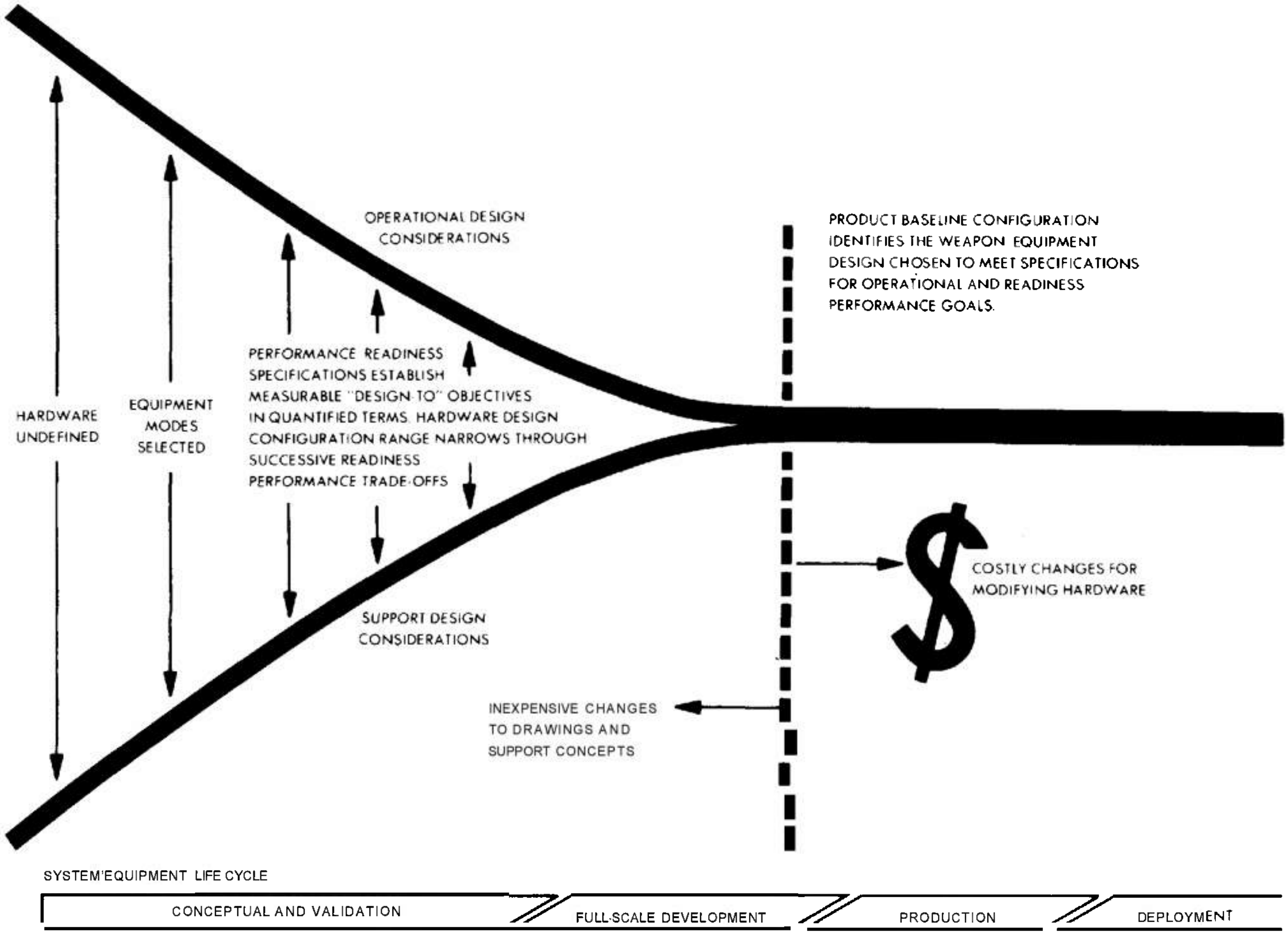


Figure 11-6. Operational and Support Design Considerations (Ref. 4)

Efficient management of Army materiel maintenance depends to a great extent on the thoroughness of the upstream maintenance engineering analyses. These are systematic, comprehensive analyses, including the projected service support environment of the materiel, and they should be conducted on an iterative basis throughout the acquisition cycle. These analyses should be the single analytical logistic effort within the system engineering process, and should be responsive to acquisition program schedules and milestones. They are a composite of systematic actions taken to identify, define, analyze, quantify, and process logistic support requirements. The analyses evolve as the development program progresses. The number and type of iterative analyses vary according to the program schedule and the complexity of the materiel. As the analyses evolve, records should be maintained to provide the basis for logistic constraints, identification of design deficiencies, and identification and development of essential logistic support resources.

11-2.3 DEVELOP LOGISTIC SUPPORT OBJECTIVES

Qualitative and quantitative logistic support objectives, developed as a result of a comprehensive maintenance engineering analysis process (see par. 5-1.1), provide baseline data for maintenance management of maintenance engineering activities. An effective maintenance management system is one that causes these data to be updated periodically and insures that materiel and support subsystem design is influenced to satisfy implicit and explicit requirements established by the data.

Logistic support objectives are established initially during the conceptual phase, and are based on operational requirements and historical data. All subsequent maintenance engineering planning provides for refinement and attainment of the objectives. Management schedules require that the objectives be refined and converted into maintenance and support parameters, and, subsequently, that the parameters be incorporated into materiel and support subsystem designs that are validated by tests.

11-2.4 USE LOGISTIC MODELS

An inherent part of an equipment maintenance management program is proper treatment of logistic support modeling. The impact of support alternatives upon systemlequipment life cycle cost, availability, equipment and manpower loading, and stocking of parts should be predicted and evaluated by use of the modeling techniques appropriate to the program. The logistic model(s) should be compatible with but should not duplicate other system engineering models. Specific models and procedures should be identified or provided by the procuring activity whenever possible.

A model is a representation of a system or function. In support modeling, the concern normally is with mathematical models, wherein mathematical relationships are used to represent equipment utilization, failures, maintenance activities, etc. (Ref. **12**). Mathematical models are categorized as either analytical or simulation models. Analytical models use exact relationships between the variables under consideration. Simulation models permit the variables to operate on the system in a random manner. For example, in an analytical model, mean values such as mean time between failures and mean time to repair are used. In a simulation model, distributions of failure rates and repair times are used, and values from the distributions are applied randomly to simulated operations.

Analytical and simulation models normally will not give precisely the same solution to a problem. This is to be expected, since the analytical model is deterministic and the simulation model is probabilistic. The analytical model provides average results that should occur over a very long period of time. The simulation model provides a series of short-term results (i.e., daily or weekly) that may vary significantly from the average results but, taken as a group over a long period of time, will provide an average value approximating that of the analytical model. Assuming the availability of appropriate input data, simulation models provide an excellent method for determining mean values and for validating means that have been determined by some other method and for all types of support analyses.

It is important to select or design the right model for the analytical work to be accomplished. Some factors to be considered are the number of variables involved in the problem, the degree of availability of accurate data pertaining to the variables, and the use of general-purpose versus custom models.

The decision concerning the scale of the model (number of variables) to be used is possibly the one decision with the most far-reaching effect on the support modeling effort. If a large-scale model is selected, the potential benefits should outweigh the additional cost of data collection and data processing. Conversely, if a low-scale model is chosen, care must be exercised to prevent the omission of highly significant data elements from consideration. The model scale normally should provide for future as well as current requirements. Therefore, if future requirements exist for a large-scale model, selection of models with capacities difficult or expensive to expand should be avoided.

The choice between using a general-purpose or a custom model depends on the data elements to be considered. When an existing general-purpose model adequately considers the pertinent data elements, its use may effect a significant savings in programming and learning costs. However, if critical data are not considered or if the application is too remotely related to the general-purpose model, a custom model should be developed to use the available data more efficiently. Sensitivity analysis may be performed with any of the models to assist the modeler in deciding whether or not the inclusion of certain data elements or the accuracy of the data will have a significant effect on the results of the model application.

The major outputs of mathematical models are data for comparison of alternative solutions to a problem. Small-scale models can be designed with optimizing features to arrive at the single best solution. When the models become more complex, as in large-scale simulation models, and the number of variables is large, the practicality of self-optimization diminishes. Typical outputs of the mathematical models used in logistic support studies include such data as availability, operational readiness, repair part usage, man-hour requirements, and system costs.

Basic data required by typical support models include information relating to failure rates, utilization, repair times, repair policy, location of repair actions, supply policy, and costs.

As an aid to the Army logistic community, the U S Army Maintenance Management Center publishes a Support Model Reference List which is updated semiannually. Current support models/techniques in use throughout the Department of the Army are listed in Table 11-3. This table also provides general information on the support areas considered by the models, and the program languages in which computerized models are written. The latest list always should be consulted for a suitable model prior to initiating development of new models to assist in accomplishing logistic support analyses.

11-2.5 DEVELOP MAINTENANCE ENGINEERING ANALYSIS DATA

Maintenance engineering management must maintain extensive data records throughout the hardware acquisition cycle to support maintenance management objectives. The primary source of the data is the iterative analyses conducted as a part of overall maintenance engineering activities. These analyses provide outputs that determine logistic support requirements. These outputs also are a source of logistic data that are applied to the system design effort in the form of design recommendations for improving maintainability and supportability, and provide data to risk analyses, effectiveness studies, and system trade-off studies.

Analyses devoted to logistic support requirements provide qualitative and quantitative data used for provisioning, maintenance planning, facility design, technical publications, support subsystem engineering, personnel and training plans, and the packaging, handling, storage, and transportation program. More specifically, analysis output documentation identifies and describes support and test equipment; facility requirements; personnel required by skill, type, and number; repair parts; and quantification of maintenance and operational support needs.

Maintenance management must be concerned with the timely identification and availability of data from maintenance engineering analysis. These are required in order to impact the design requirements effectively, provide a basis for timely development of support resources, and insure the availability of the total support resources (technical data, facilities, support and test equipment, etc.) with the operational materiel. Maintenance management, therefore, must insure that within the posture of the materiel acquisition cycle, the maintenance engineering analysis tasks are scheduled to insure prompt development of support resource data and requirements in relation to the design schedule and program data availability. Maintenance management, in relation to the maintenance engineering effort, should insure that formal program reviews are scheduled for the review of the maintenance engineering analysis data, and that development of the total maintenance resource technical data package has been scheduled realistically in relation to the materiel development schedule.

11-2.6 UPDATE MAINTENANCE ENGINEERING ANALYSIS DATA

Maintenance engineering analysis data continuously must reflect the current materiel design and support requirements compatible with the design. The requirements for change are derived from a variety of sources. Some typical events that generate requirements for data updating are design changes, support subsystem changes, more intensive analyses, test and evaluation results, and initial provisioning results.

11-2.7 SELECT SUPPORT AND TEST EQUIPMENT

Maintenance engineering determination of support and test equipment requirements impacts maintenance management. Emphasis

TABLE 11-3. LIST OF SUPPORT MODELS/TECHNIQUES (Ref. 5)

Model/Technique	Computer Language	Support Areas Considered*											
		Reliability	Maintainability/ Downtime	Availability	Initial Provisioning/ Supply Requirements	Support Equipment	Maintenance Policies	Personnel Requirements	Maintenance Float	Life Cycle Support Costs	Other Cost Considerations	Mission Requirements	Transportation Criteria
Achieved Availability	FORTRAN IV	X	X	X									
ALPHA 4140.39 Simulator	FORTRAN IV				X						X		
AN/TSQ-73 Life Cycle Simulation	FORTRAN IV	X	X		X			X			X		
Armored Reconnaissance Scout Vehicle Support Phase Cost Model	FORTRAN	X	X		X	X	X	X		X		X	X
Army Depot Repair and Overhaul Simulation Model	SIMSCRIPT 1.5	X	X			X	X	X					
Army Depot Transportation Simulation Model	SIMSCRIPT 1.5	X	X			X	X	X				X	X
Army Direct Support/General Support Simulation Model	SIMSCRIPT 1.5	X	X		X	X	X	X	X			X	X
Army Organizational Maintenance Simulation Model	SIMSCRIPT 1.5	X	X	X	X	X	X	X	X			X	
Automated Maintenance Factor Determination Technique	CONVERSATIONAL FORTRAN	X										X	
Cost Analysis of Maintenance Policies Model	FORTRAN IV	X	X	X	X	X	X	X	X	X	X	X	X
Depot Capability Evaluation Technique	FORTRAN IV					X		X					
Depot Capacity Analysis Program	FORTRAN IV and COBOL					X		X					

*See footnote at end of table.

TABLE 11-3. LIST OF SUPPORT MODELS/TECHNIQUES (Ref. 5) (Cont'd)

Model/Technique	Computer Language	Support Areas Considered*											
		Reliability	Maintainability/ Downtime	Availability	Initial Provisioning/ Supply Requirements	Support Equipment	Maintenance Policies	Personnel Requirements	Maintenance Float	Life Cycle Support Costs	Other Cost Considerations	Mission Requirements	Transportation Criteria
Determination of the Optimum Replacement Time for a System Composed of n Independent Failing Subsystems	FORTRAN IV	X	X								X		
Determination of Transient Availability Under Dependent Failures or Finite Replacement Times	FORTRAN IV	X	X	X			X						
Economic Evaluation of Maintenance Support Alternatives	FORTRAN IV	X	X		X		X	X		X		X	
Engineering Change Cost Benefit Evaluation Procedure	BASIC	X	X					X	X		X		
FAMECE Integrated Logistic Evaluation Simulation Model	GPSS	X	X	X	X	X	X	X	X			X	
FAMECE Integrated Logistic Support Analytic Models	FORTRAN IV	X	X	X					X			X	
Fleet Management System Model	FORTRAN IV and COBOL	X	X	X	X	X	X	X	X			X	
Forecast of Schedule/Cost Status Utilizing Cost Performance Reports of the Cost/Schedule Control System	FORTRAN IV										X		
Generalized Electronic Maintenance Model	FORTRAN IV	X	X	X	X	X	X	X	X	X	X	X	X

*See footnote at end of table.

TABLE 11-3. LIST OF SUPPORT MODELS/TECHNIQUES (Ref. 5) (Cont'd)

		Support Areas Considered*:											
Model/Technique	Computer Language	Reliability	Maintainability/ Downtime	Availability	Initial Provisioning/ Supply Requirements	Support Equipment	Maintenance Policies	Personnel Requirements	Maintenance Float	Life Cycle Support Costs	Other Cost Considerations	Mission Requirements	Transportation Criteria
Life Cycle Analysis Program	FORTRAN and COBOL	X	X	X	X	X	X	X	X	X	X	X	X
Logistic Cost Analysis Model	FORTRAN IV	X	X	X	X	X	X	X	X	X	X	X	X
Models of the Army Worldwide Logistic System	FORTRAN IV and GASP	X	X	X	X	X	X	X	X	X	X	X	X
Modified Computerized Relative Allocation of Facilities Technique	FORTRAN IV and ASSEMBLY					X		X					
Overhaul Facility Simulator	BASIC	X	X	X		X		X			X	X	
Replacement Unit Repair Level Analysis Model	FORTRAN IV	X	X	X	X	X	X	X		X			X
Simulation and Gaming Methods for Analysis of Logistics	COBOL and FORTRAN IV	X	X		X	X	X	X	X			X	X
System Availability Model for Communications	FORTRAN IV and COBOL	X	X	X								X	
System Analysis Repair Cost Model	Not applicable	X	X	X			X			X			X
Techniques for Determining Optimal Operational Readiness Float	FORTRAN IV	X	X	X					X		X		
Techniques for Determining Repair Cycle Float	Not applicable	X	X	X					X				
Overhaul Simulation Model	FORTRAN IV		X		X		X		X			X	

* An X indicates that the support area is considered explicitly either through required input data or model calculations.

should be placed on this activity, since an incomplete or inadequate investigation or analysis can lead to unnecessary expenditures in development and support funds. TMDE should be selected that will satisfy operational requirements at lowest life cycle costs. Two basic actions that will assist in accomplishing this goal are to avoid unnecessary devlopment of TMDE and to select TMDE that has minimal support requirements.

Careful screening of specifications for existing inventory equipment is necessary to insure maximum use of in-service assets and elimination of duplicate development of similar items of TMDE for different system applications. The Army has issued a test, measurement, and diagnostic equipment register index (Ref. 6). The purpose of the index and the companion register is to provide Army development, procurement, maintenance, and user activities with test, measurement, and diagnostic equipment (TMDE) technical item descriptions for use in determining which proposed or existing TMDE can be applied to the TMDE requirements of new equipment programs. Details of the contents of the index and register are contained in par. **9-1.2.3.2.** TMDE considerations with regard to support requirements are discussed in par. **9-2.5.3.**

11-2.8 IDENTIFY TRANSPORTATION AND HANDLING REQUIREMENTS

Another facet of maintenance engineering that plays a role in maintenance management is the generation of transportation and handling requirements. Identification of these requirements results from the analyses conducted by maintenance engineers throughout the materiel life cycle. The transportation analysis variables can be categorized into two broad types: hardware and transportation. Included in the first type are hardware size, weight, cost, demand rate, maintenance concept, criticality, etc. The transportation variables include mode (i.e., air, rail, water), freight cost, shipping times, pilferage factors, etc.

Discard-at-failure items move one way—from manufacturer to user; repairable 'items move two ways—from source to user and back to some point of repair. Accordingly, the benefits to be gained from optimizing transportation requirements normally are greater for a repairable item than for a disposable item.

In general, most hardware needs are fulfilled in a peacetime environment. This environment is conducive to a relatively smooth and coordinated effort in transporting materiel from origin to point of use. However, the wartime environment, when speedy materiel distribution must be obtained with less than ideal transportation systems, is the other factor to be addressed in the transportation analysis. This includes considerations such as packaging, handling, marking, storage, pipeline length, inventory quantities, and transportation system reaction time. All these factors are integrated into a transportation plan that serves the normal peacetime requirements and has the inherent ability for rapid and smooth transition to meet wartime requirements.

11-2.9 DEVELOP TECHNICAL DATA

In general technical data comprise audio and visual presentations of data required to guide personnel in performing operation and support tasks. Because maintenance operations cannot be performed without these data, the data are of critical interest to maintenance management.

Some of the most common categories of technical data are operating and maintenance manuals, modification instructions, provisioning and facility information, and calibration procedures. The development of all of this documentation (and other types) depends upon maintenance engineering activities. The maintenance concept and maintenance level assignments, task analyses, repair level analyses, etc., accomplished by maintenance engineering generate the raw data that are required to prepare technical data, and concurrently define the range and depth of the technical data that are required.

Maintenance engineers should monitor the equipment technical data plan and make recommendations when applicable. This plan presents a systematic process for developing the technical data necessary to operate, maintain, modify, supply, repair, and overhaul materiel. The plan is included in the plan for logistic support to assure that the technical data are ready for use when the end item initially is issued to the user.

11-2.10 IDENTIFY FACILITY REQUIREMENTS

Another basic step in the maintenance management process is the analyses of facility requirements by maintenance engineering personnel. These analyses identify the facilities required to support the materiel throughout system testing, training, operations, and maintenance. Preliminary information developed during the conceptual phase is refined until contractual commitments must be made. Facility considerations include requirements for mobile, portable, and air transportable vans, mobile maintenance facilities, shops, training facilities, supply storage, and bulk storage containers, as operational, maintenance, and support concepts dictate. Changes and improvements in materiel design are reflected in facility requirements when appropriate. Realistic scheduling makes optimum use of facilities and at the same time permits timely performance of maintenance functions. Facility recommendations include facility identification and description, facility design criteria, facility costs, and lead time. This area of maintenance engineering activities should be monitored carefully, since it can have a major program cost impact.

11-2.11 IMPLEMENT PERSONNEL AND TRAINING PROGRAM

As a result of maintenance engineering analysis, recommendations are made regarding the personnel, training, and training material required for the support of the system/equipment. Coordination is maintained with cognizant design activities so that applicable design changes are reflected in the personnel and training plan. Analysis provides identification of the requirements for trained operator, support, and instructor personnel. Personnel and training data resulting from maintenance engineering activities include personnel quantities needed, skill levels, skill specialties, training requirements, training facilities, and training materials.

One of the key elements of the maintenance management function is insuring that the maintenance support program and the total technical data package are developed and available in a timely, adequate, and cost-effective manner to support the operational hardware. As such, maintenance management should insure that an adequate personnel and training program has been established for the transfer of knowledge required for operation and maintenance of the materiel from the developer to the military user. This management function should insure interface between responsible organizations, establishment of qualitative and quantitative personnel requirement information, development and implementation of new-equipment training courses, and conduct of a study on training aids and devices, as applicable. The effectiveness of the program depends on the implementation of training in an adequate time frame prior to materiel deployment to insure that required personnel are trained in operation and maintenance of the fielded materiel.

11-2.12 REVIEW HISTORICAL DATA (Ref. 7)

Historical data review is part of the maintenance management process. Historical data, when carefully examined, provide invaluable information about the maintenance requirements and support characteristics of new materiel being developed if the data are from items similar to those currently under development. Analysis of past experience pinpoints features that have or have not worked on existing items and:

a. Discloses major downtime contributors

b. Indicates high failure rate items

c. Identifies design features that benefit support

d. Identifies prime contributors to high cost

e. Indicates maintenance man-hour requirements

f. Helps identify trouble spots

g. Provides parameters for simulation models.

These data establish a baseline of values with which to compare a new development. This baseline may indicate areas that require a new design approach or a departure from traditional maintenance concepts. The data also may disclose trends in the maintenance concepts or support subsystems which are being applied to other new items.

Foremost in importance for a successful historical data review is access to valid experience data. These data sources have been identified in par. 8-1.1. Other important sources are industrial data, field data, test data, and a range of data from the Navy and Air Force.

11-2.13 PERFORM COST ANALYSIS

Selection of cost factors and the subsequent cost analyses that are made after a cost factor survey are important steps in the maintenance management process. A detailed discussion of cost factors and cost modeling is contained in par. 8-5. A brief description of the cost analysis data requirements and expected results is included here to illustrate the interface of cost in the maintenance management of Army materiel.

Cost analysis is a tool for estimating the economic impact of proposed courses of action. It is an analytical process used to estimate the cost of development, procurement, operation, and maintenance of equipment. These costs can be measured in terms of manpower, equipment, facilities, and supplies, as well as in dollars. Cost analysis can improve the management and allocation of Army resources and assist in evaluating program alternatives.

Cost estimating relationships are developed from the historical data review. The data include cost, as well as characteristics–such as size, weight, speed, complexity, reliability, and maintainability–that are pertinent to the item under consideration.

Statistical techniques such as linear regression and multiple regression analysis (see par. **6-4**) can be used to develop complex relationships. Frequently, it is desirable to limit the number of characteristics being considered in the cost estimating relationship in order to prevent the solution from becoming overly complex and because the influence of the predominant characteristics overshadows the influence of many minor attributes. Also, the influence of the cost-related characteristics tends to change as the item moves through the preproduction, production, and operational phases of the equipment life cycle. Therefore, separate cost estimating relationships usually are desirable for each of these phases.

One of the greatest problems encountered in cost analysis is obtaining sufficient and accurate data. The basic data compiled to support the requirements of the cost analysis should be collected in sufficient quantity to provide significant sample sizes of the various system characteristics and cost parameters being studied. Every effort should be made to acquire sufficient data from actual surveillance of systems in an operational environment. If, however, adequate data of this type are not available, it may be necessary to resort to various estimating techniques. The data should be obtained from an operational environment corresponding as closely as possible to the probable operating environment of the item under consideration. Many of the factors affecting the cost of developing, procuring, operating, and maintaining an item are dynamic. Therefore, timely collection of input data is required if the cost analysis is to depict current conditions in the system.

The data associated with cost analysis are as follows: standard cost factors relating to transportation, facility space, consumable resources, inventory maintenance, support equipment maintenance, provisioning, disposal, maintenance data, discount rate, and escalation; item costs relating to personnel cost per manhour, repair part acquisition, consumable acquisition, support equipment and tool acquisition, and documentation; and total costs relating to repair parts, maintenance personnel, operator personnel, training, training equipment, support equipment acquisition and maintenance, facilities, and transportation and handling.

11-2.14 ESTABLISH TIME FACTORS

Time factors play a role in maintenance management. These factors must be developed by maintenance engineering throughout the development cycle in the form of time analyses. Time analyses of maintenance are the basis for determining:

a. System downtime as an influence on system 'effectiveness

6. Maintenance man-hour requirements as a means of measuring the logistic burden caused by the item

c. Maintenance time standards for maintenance planning and measurement of personnel performance.

Examples of some types of functions that are time critical are functions, such as system checkout or inspections, which affect system reaction time; functions, such as fueling, servicing, or system configuration changes to meet a different mission assignment, which affect mission turnaround time; and functions, such as corrective maintenance, which affect availability. These analyses yield time constraints on performance and design requirements for trade-off decisions. They also play an important role in determining whether automatic or manual methods are required to perform the function.

The analysis also must address the logistic and other delay times in the maintenance/repair cycle. Such delay times are more a function of the maintenance and supply environment than equipment design. Some of these delay times have a direct effect upon system effectiveness. The time required to obtain an item and prepare for a maintenance action is an example. This downtime adversely affects system availability, which, in turn, adversely affects system effectiveness (par. 6-5.1).

11-2.15 USE LIFE CYCLE COST MODELS

Maintenance management, as it applies to maintenance engineering responsibilities, includes the development and use of life cycle cost models to aid in the decision process. This step, although discussed last, will occur whenever the need is identified for a life cycle cost analysis. This subject is addressed in pars. 8-5 and 11-2.4. The primary points to reiterate are that life cycle costs are playing a greater role in the system selection process and that several types of general-purpose cost models are available to the maintenance engineer (see Table 11-3). In order to avoid duplication of effort and unnecessary expenditure of funds, the maintenance engineer should review previously developed models for applicability to his needs. Model selection criteria described in par. 11-2.4 for logistic models apply to life cycle cost models.

11-3 MAINTENANCE MANAGEMENT CONTROL DURING SYSTEM DEVELOPMENT

Maintenance management control during logistic support development includes approval of decisions regarding maintenance concepts, management by means of planning documents, use of historical data and cost analysis in the decision process, assessment of contract compliance, in-process reviews, and type classification actions.

11-3.1 INTEGRATED LOGISTIC SUPPORT CONCEPT (Ref. 4)

The development of logistic support for hardware acquisition requires the same intensive management and control as the hardware design process requires. Present-day practice is to plan for and manage the support aspect of the acquisition as part of an overall integrated logistic support approach. An understanding of the integrated logistic support concept and its basic objectives will aid the maintenance engineer in management and control of activities that impact the evolving support subsystem.

The integrated logistic support concept envisions the definition, optimization, and integration of support by systematic planning, implementation, and management of logistic support resources throughout the system life cycle. The concept is realized through the proper integration of logistic support elements and resources with each other and through the application of logistic considerations to the decisions made on the design of the hardware system and equipment as a part of the system engineering process.

Organizations directly responsible for the operation of military systems and equipments realize that support problems are a limiting factor on the operational availability of materiel. Effort is expended in the design and the support planning to develop ways to increase mean time between failures, decrease periodic maintenance, and reduce maintenance downtime. Operational commanders monitor the statistics on those items of equipment which are not operationally ready because of maintenance or supply problems. They recognize the importance of having adequately trained personnel to operate the equipment properly and to maintain it efficiently in order to reduce the number and frequency of failures and to reduce the adverse effect of such failures and maintenance, time on operational readiness. In addition, they realize the importance of adequate facilities and support equipment to maintain the operational readiness of their equipment.

The integrated logistic support concept must be applied throughout the acquisition cycle to insure that systems are designed to meet operational requirements economically. Systematic consideration of the solution to the problems of support must begin in the conceptual phase and continue thereafter. The lack of timely and systematic planning will adversely affect operational availability and .cost of ownership.

Under the integrated logistic support concept, the importance of trading off operational and support requirements from the earliest phases of the life of a system has been recognized. **As** DoD Directive **4100.35** states: "Over the life cycle of a system, support represents a major portion of the total cost, and is sometimes the principal cost item." (See Ref. 8.) By integration of logistic considerations into the conceptual planning and through the entire design and development process, either support costs during the operation may be significantly reduced, or operational availability of the system may be increased without a significant increase in cost. In addition to integrating support planning into the entire design and development process, it is also fundamental to the integrated logistic support concept that logistic support resources must be integrated with each other into a total support subsystem. When requirements for a support resource category are changed or a change is proposed, the effect on all other support resources and on the total system must be considered formally and necessary adjustments made.

In applying the concept of integrated logistic support to a systemlequipment acquisition, it is important to maintain a proper perspective and bear in mind that logistic support is not an end in itself, but exists only to support the operation of the system/equipment to which it is related. The support problem will vary according to the complexity and value of the system/equipment. Planning for support must be tailored to each acquisition individually—major acquisitions, less-than-major acquisitions, off-the-shelf items, and modification programs.

It is necessary also to bear in mind that in any acquisition which includes development, two entirely different types of effort are involved: first is the conceptual and broad planning stage, and second is the period from full-scale development through final disposition, in which the actions contemplated in the first stage are refined and implemented. Just as support planning must be tailored to the type of acquisition, it also must be tailored to the time phasing of the acquisition process.

The first part of the logistic problem in a system acquisition cycle is to establish basic characteristics which will enable the operational requirements to be achieved economically. Management must keep the operational mission clearly in view during the early stages, and should carefully define and schedule the efforts that must be accomplished prior to full-scale development. Once the basic logistic system characteristics are formulated, they must be stated to the design engineer in a "design to" or "design constraint" fashion. When requirements are stated in this format, they may be used in analytical and trade-off studies. In the development of logistic support concepts and early planning for support, management must assure that logistic and design personnel work together in an atmosphere of maximum cooperation and liaison. Thus, the integrated logistic support concept function must be identified closely as an integral part of the total system engineering process.

The logistic effort in the early stages must be confined to development and formulation of inclusive but broad logistic plans and support characteristics. The result should be a "roadmap" of the specific steps to be taken, when they are to be taken, and the extent of detail as the development progresses and the design matures. The detailed planning and preparation of detailed data packages must be deferred until the configuration of the hardware has been reasonably stabilized. Detailed support planning, which is accomplished prior to the establishment of the basic configuration and is dependent on that configuration, almost certainly will require extensive rework to become valid and usable.

Integrated logistic support planning requires considerable management attention. Conceptual planning for integrated logistic support is accomplished initially by the Government for each acquisition. Subsequently, for major materiel acquisition programs, the plan is expanded progressively and updated by joint Government/contractor efforts in phase with major program events. The function of the plan for logistic support is to identify the actions to be accomplished, assign responsibilities, and establish milestones. It accounts for the interaction of events and activities; provides for Government/contractor management and review policies; establishes logistic support management information reporting requirements; and provides for the definition, integration, and subsequent acquisition of support resources. Initial planning must be sufficient to establish the scope of integrated logistic support activities for the initial phase of the acquisition process, and generally is limited to the consideration of special problems. During each phase, the level of detail in integrated logistic support planning must be sufficient to provide support for equipment that is deployed or used during that phase. It must establish the scope and depth of activities to be accomplished in the succeeding phase and should make provisions for an orderly transition to the succeeding phase. Careful attention must be given to lead time requirements and to integrated logistic support activities that are prerequisites to the accomplishment of other activities; e.g., the maintenance concept should be established before the support and test equipment is designated.

Integrated logistic support planning reaches operational maturity during the production/deployment phase, and implementation is accomplished by the procurement or activation of support resources in accordance with the schedule requirements. It is essential that the activation and implementation schedule permit systematic definition and contractual coverage of the scope and depth of support resources in a time frame that will permit their acquisition.

To organize effectively for the application of integrated logistic support, it must be recognized that integration of the logistic considerations into the hardware system being acquired requires analytical and developmental logistic activity phased with the prime equipment analytical and development activity. This requirement dictates a project organization that facilitates the concurrent accomplishment of the two developmental activities.

11-3.2 DETAILED SUPPORT PLANNING

The Army's maintenance management task is complex. Support must be planned and provided to a broad range of materiel types, with a diversity of deployment locations and missions. Management control is complicated by distances involved and inherent limitations in communication channels through which a feedback of vital experience and performance data must be retrieved, evaluated, and acted upon.

Some of the key goals of support planning are to:

a. Assure the readiness of the Army's priority combat equipment

b. Give combat support that will result in maximum combat effectiveness

c. Organize effort in support of combat force needs

d. Assure economy of effort.

The objectives of support planning, from a maintenance management standpoint, include the reduction of support requirements and costs to a level consistent with operational readiness requirements. This objective cannot be met by routine observation of support needs. Its attainment requires systematic evaluation of materiel design and support characteristics as a part of the system engineering process by technically qualified specialists. This involves the iterative assessment of the impact the design will have on specific technical and support requirements. The effectiveness of such an assessment and its influence on design are dependent on the meaningful application of management and control techniques during all phases of acquisition.

Support planning requires a close and dynamic working relationship between system engineering and detailed design and maintenance engineering personnel. It involves repeated review and refinement of emerging support characteristics and their probable impact on design requirements, including operational readiness performance characteristics. Support performance descriptors, in the form of maintainability and reliability characteristics and projected support requirements, provide a basis on which design of the support subsystem can be defined and support planning can be accomplished in terms of assigned tasks and needs. Key characteristics of the support subsystem should be expressed in terms of quantitative values reflecting a measure of system availability, utilization, downtime, turnaround, crew requirements, maintenance man-hours per operating hour, defined constraints, etc., as appropriate to the equipment type and intended use. The performance of the support subsystem under development then can be evaluated in terms of finite measurements.

The basic support planning document is a plan for logistic support which is a part of a materiel development plan (see par. **2-2.3.2**). The plan for logistic support is designed to identify, schedule, and control all the actions required to provide timely and economical support of materiel. It is comprised of three top-level plans: schedule of logistic support planning; basis for logistic support planning; and elements of logistic support. Within the elements of logistic support are a maintenance plan and plans pertaining to:

a. Support and test equipment

b. Supply support

c. Transportation and handling

d. Technical data

e. Facilities

f. Personnel and training

g. Logistic support resource funds

h. Logistic support management information.

The bases for the foregoing plans are established in the conceptual phase, and the plans are continuously updated until each is implemented. The economy and effectiveness of the support subsystem are derived directly from the maintenance engineering analysis documents on which these plans are based and refined, and from the management control exercised during their implementation. These documents control the expenditure of far more defense funds than the research, development, procurement, and production funds associated with the materiel for which the support is planned. Moreover, the documents, in large part, control the effectiveness that can be achieved by the deployed materiel. In view of these facts, the importance assigned to maintaining a high degree of excellence in the management and accomplishment of support planning cannot be overemphasized.

11-3.3 COST ANALYSIS (Ref. 9)

The use of cost analyses as an inherent part of the maintenance engineering process can exert considerable influence on the decision-making process as it affects maintenance. As noted in Chapter 8, cost analyses are not an end unto themselves; they are inputs that assist management or technical decision-makers to make the right decision concerning resources. The techniques used to conduct cost analyses are many and vary in complexity. Some of these are oriented primarily toward determination of system life cycle costs.

Lower level cost analyses can assist maintenance engineering management make decisions relative to details of design throughout a program life cycle. Three basic categories of costs are significant to these detailed analyses. They are:

a. Initial Costs. These are the costs associated with introducing materiel into the Army inventory. These costs include:

(1) Research and development

(2) Industrial (procurement and production)

(3) Supply and maintenance

(4) New technical data

(5) New part number cataloging

(6) Training of instructors and unit personnel

(7) New tools, facilities, and test equipment.

b. Phase-in Costs. These are the costs associated with support of new equipments currently being phased into the Army inventory, and support of old equipments until required densities of new equipment are attained.

c. Recurring Costs. These are the costs associated with support of an item once its expected density is reached. These costs include:

(1) Holding inventory

(2) Ordering

(3) Replenishment

(4) Technical data

(5) Training of replacement personnel

(6) Tools, test equipment, and facility upkeep

(7) Maintenance labor and maintenance overhead.

These cost factors are considered in the overall determination of the design and support subsystem concepts. Through analytical processes, areas requiring improvement—such as design, repair part stockage, training, maintenance techniques, and other support-related parameters—may be identified and optimized in terms of design/support cost-effectiveness.

11-3.4 HISTORICAL FIELD DATA (Ref. 3)

Historical field data are among the most significant inputs to maintenance engineering management during system development. These data are accumulated through many sources. They have commonality, however, in the fact that they relate past experience to the logistic support requirements of a new acquisition. Primarily, historical field data encompass supply, maintenance, and operational information from existing systems. Typical sources are Army maintenance management data, other military services, contractors, Army commodity commands, and Army staff offices such as the Office of the Army Comptroller.

Typical input documents are maintenance and operating reports, technical reports, combat records, and field exercise reports. These documents can yield such technical data as subsystems or components that have a potential for high failure rates, major downtime contributors, and design features that may cause degradation of the logistic support system. Additionally, they yield nontechnical data in the form of gross requirements for logistic support resources such as manpower, equipment, transportation, and facilities.

Although the bulk of historical field data is service-generated, valuable data are also accumulated by contractors. This is true particularly during contractor test programs. The following examples of contractor record-keeping responsibilities were extracted from an integrated support plan for an Army air defense weapon system entering the advanced development phase:

a. Failure Reporting. Contract maintenance personnel will report equipment failures in accordance with the provisions of the product assurance test, demonstration, and evaluation plan. Trouble and failure reports will be returned through the failure reporting and corrective action system to update *MTBF* and *MTTR* predictions and other data stored in the maintenance data system.

b. Supply Information. Reporting of repair material usage will be in accordance with the requirements of the repair part and support plan, which calls for weekly reports of repair part usage to be forwarded to the Provisioning Section to update applicable repair part inventory lists. Discrepancies and/or omissions in the repair part lists will be documented and reported.

c. Historical Records. Historical records will be kept in the test logs described in the reliability test, demonstration, and evaluation plan and the supply and maintenance report, which is an output of the automated inventory control system. Briefly, test logs will be maintained on all equipments to include those used for maintenance support. These logs will provide a historical record of equipment utilization and maintenance. The supply and maintenance reports will list supply and maintenance transactions against each contract end item, including field maintenance test equipment.

Historical field data related to cost also are available to the maintenance engineering manager for use in trade-offs and cost-of-ownership analyses that are required during system development. The Army has made considerable progress in recent years toward collecting the data that reflect real-world historical operation and maintenance costs. These costs are available in documents issued by the Office of the Army Comptroller and the Army Field Operating Cost Agency (Ref. 10).

Finally, historical field data are included in The Army Maintenance Management System. These records are in the form of maintenance and operating reports and equipment logs. To the maintenance engineering manager who may be planning support for new materiel, these historical records point out the equipment that has required the greatest maintenance effort, thereby alerting planners to this fact when generic designs are involved.

11-3.5 CONTRACT COMPLIANCE THROUGH MAINTENANCE EVALUATION

Maintenance evaluation is the total maintenance engineering process of analysis, demonstration, test? and other activities used to establish and satisfy materiel support requirements. One maintenance evaluation activity is to insure that all program maintenance-related efforts are in compliance with the contract.

Contracting trends indicate increasing emphasis and awareness, on the part of procurement activities, of the role maintenance engineering plays in major system acquisitions. In recent years, procurement of equipment has been based on life cycle cost, which includes not only the acquisition cost, but the operation and maintenance cost during the service life of the equipment. This fact was brought about by the realization that operation and maintenance cost was a major contributor to the total life cycle cost. As a result, present-day contracts normally require an evaluation of the maintenance characteristics of the equipment, either through test, demonstration, or the analysis process.

The maintenance characteristics to be evaluated derive from quantitative and qualitative requirements incorporated in the system and end item specifications. These detailed requirements reflect the broader requirements that were established initially by the required operational capability document.

Table 11-4 is an extract from an equipment specification for a complex transportable ground power station associated with a field artillery missile system. The specification illustrates a partial listing of the detailed quantitative and qualitative maintenance requirements for the item, and defines the maintenance levels and percentage of maintenance to be performed at each level, the quantity of personnel for preventive maintenance, and the special test and evaluation requirements.

TABLE 11-4. MAINTENANCE-RELATED PORTIONS OF SPECIFICATION FOR ARMY FIELD ARTILLERY MISSILE SYSTEM GROUND POWER STATION

3.1.2.2 *Maintenance requirements.*

3.1.2.2.1 *Maintainability* The item shall be designed and fabricated for ease and economy in all maintenance functions in accordance with AR 705-50 and AMCP 706-134. Maintainability of design shall be implemented in accordance with MIL-STD-470. Maintainability as used herein is defined qualitatively as the characteristic of design and installation that makes it possible to operate with a minimum total expenditure of maintenance effort where scheduled or unscheduled maintenance is performed in accordance with prescribed procedures and resources.

3.1.2.2.2 *Maintenance times and repair cycles.* Maintenance and repair cycles for the item shall consist of preventive and corrective maintenance as defined in MILSTD-721 and shall be as follows:

3.1.2.2.2.1 *Preventive maintenance.* The item design shall be such that all tasks can be accomplished by two organizational maintenance personnel and contact team personnel. The following are the preventive maintenance cycles and active time requirements.

(a) Daily preventive inspection shall be accomplished in 0.5 hr.

(b) One hundred hour preventive maintenance inspection shall be accomplished in 3.15 hr in addition to 8.3 hr by contact team personnel.

(c) The monthly preventive maintenance inspection shall be accomplished in 0.7 hr.

(d) The quarterly preventive maintenance inspection shall be accomplished in 5.1 hr (includes 100 hr and 50 hr inspections which are applicable).

TABLE 11-4. MAINTENANCE-RELATED PORTIONS OF SPECIFICATION FOR ARMY FIELD ARTILLERY MISSILE SYSTEM GROUND POWER STATION (Cont'd)

(e) The semiannual preventive maintenance inspection shall be accomplished in **1.0** hr by contact team personnel (not including quarterly inspection which is applicable at this time).

3.1.2.2.2.2 *Corrective maintenance.* The Mean Corrective Maintenance Time M_{ct} requirement of the item is expressed by overall M_{ct} and site restoration M_{ct}. The overall M_{ct} of the item shall not exceed **3.8** hr, which includes all field and site corrective maintenance. Site restoration M_{ct} shall not exceed **1.0** hr to include a maximum of **72** percent item replacement.

3.1.2.2.2.3 *Categories of maintenance.* Categories of maintenance for the item shall be as defined in AR 750-1.

3.1.2.2.2.4 *Level of diagnosis.* The item design shall be such that it complies with the following requirement:

(a) Site level: **28** percent of all item failures shall be correctable on site.

(b) Rear level: All item failures shall be correctable at rear area.

3.1.2.2.3 *Service and access.* Service and access design requirements for the item shall be as follows:

3.1.2.2.3.1 *Electrical.*

(a) Access provisions shall be provided for connecting electrical power to the gas turbine engine analyzer. Two analyzer cables are lugged terminals.

(b) With the item mounted on the M656 vehicle, the batteries shall be mounted such that they can be extended and retracted for maintenance while electrically connected. Mounting shall be such that they can be removed and replaced within 0.75 hr.

3.1.2.2.3.2 *Conditioned air.*

(a) Accessibility to the water separator shall be adequate through a hinged access opening to disassemble and replace the water separator filter bag.

(b) The air purification unit in the pneumatic system shall be mounted such that it is capable of full extension and retraction without any disconnecting.

3.1.2.2.3.4 *Gas turbine engine.* The engine to gearbox drive design shall be such to permit engine removal without removing the gearbox assembly.

3.1.2.2.3.5 *Enclosure.*

(a) The enclosure top shall contain hoisting provisions for both the top and the complete item.

(b) The enclosure top shall be secured with quick-release captive hardware.

3.1.2.2.3.6 *Tools.* The power station shall be capable of being maintained at the organizational and field levels of maintenance with the use of only standard mechanical hand tools. Standard tools are defined as tools available in the Federal Supply System.

3.3.7 *Interchangeability and replaceability.* Each assembly, subassembly, or piece part which is subject to replacement at any maintenance level shall be an interchangeable item. Interchangeable items are items having the same manufacturer's or Federal stock

TABLE 11-4. MAINTENANCE-RELATED PORTIONS OF SPECIFICATION FOR ARMY FIELD ARTILLERY MISSILE SYSTEM GROUND POWER STATION (Cont'd)

number which, without selection, may be substituted for one another, and, without adjustment or modification to the substituted item or to the equipment into which it is substituted, shall provide the same physical and functional characteristics required of the original items.

3.3.11.2 *Storage Zife.* The item shall be designed for a maximum practical storage life, but not less than those times specified as follows:

(a) Under cover with controlled humidity and temperature conditions for **4** yr.
(b) Under covered field storage with no environmental control for 1 yr.
(c) No maintenance during storage shall be required nor shall servicing be required, other than servicing the batteries, upon depreservation of the equipment and returning it to active use. Replacement of O-rings, seals, and grease-packed bearings will be accomplished prior to placing the power station into service after storage, as specified in ANA Bulletin **438.**

4. TEST AND EVALUATION

4.1 *Test/verification.* Except as otherwise provided in **4.2,** formal verification of performance and design of the item shall be demonstrated by satisfactorily completing the following test/verification functions:

(a)	Engineering test and evaluation	**4.1.1**
(b)	Qualification inspection	**4.1.2**
(c)	Reliability verification	**4.1.3**
(d)	Maintainability tests and analyses	**4.1.4**
(e)	Engineering critical component qualification	**4.1.5**
(f)	Visual examination and performance test.	**4.1.6**

* * * * * * *

4.5 *Rejection.* Unless otherwise specified, the following shall constitute cause for rejection of the item:

(a) Failure to meet all requirements specified herein
(b) Failure to perform as required in any of the tests in accordance with the quality assurance provisions specified herein
(c) Deterioration resulting from testing in accordance with the quality assurance provisions specified herein which make the item unsuitable for its intended use.

The maintenance engineer, during the total evaluation process and through interface with other functional groups, must insure that the maintenance concept, maintenance support resources, and hardware design selected will insure the attainment of the quantitative and qualitative specification requirements. To insure this attainment, the maintenance engineer should be an integral participant in development of quantitative specification requirements such as mean time to repair, as well as qualitative requirements related to interchangeability, standardization, tool and test equipment, and other maintenance-related factors.

Conducting the maintenance analysis throughout the system acquisition cycle will insure timely evaluation and identification of problem areas, and correction of design or maintenance support deficiencies. The results of the other test and evaluation activities are used, as applicable, by the maintenance engineer to aid in the maintenance evaluation process for contract compliance.

Noncompliance with contract requirements must be identified and corrected early in the development phase. As a general rule, the further the design has progressed, the more costly and more difficult are the design changes. As delineated in the specification example (Table **11-4**), failure to meet the maintenance requirements may be cause for rejection of the item. A determination of noncompliance may result in redesign, retest, waiver, or total rejection of the item, depending on the degree and severity of the noncompliance.

Maintenance engineering activity must be managed carefully, from development of the required operation capability, through establishment of quantitative and qualitative specification requirements for system and end items, the conduct of detailed maintenance engineering analysis effort, participation in design/support decisions, and involvement in maintenance-related test/verification programs. Effective maintenance management control during this logistic support development should insure that the maintenance evaluation process is conducted in a timely, efficient, and comprehensive manner, and insure contract compliance with all maintenance-related contractual provisions.

11-3.6 IN-PROCESS REVIEWS (Ref. 11)

Formal reviews conducted at critical points during a materiel acquisition program assist in maintenance management. The reviews are conducted to evaluate the status of the program, accomplish coordination among affected agencies, arrive at timely decisions, and assure ultimate acceptability of the materiel for use by the Army.

The reviews provide all agencies involved in a program the opportunity to analyze progress and problems from their respective points of view, and to issue coordinated direction for future program actions. The ultimate results are a reduction in development time and costs and more effective materiel.

The management levels that participate in reviews are governed by the magnitude and importance of the materiel program. Programs are designated major and nonmajor. Strictly speaking, only nonmajor programs are subjected to in-process reviews (IPR's). Major programs are subjected to reviews termed Defense Systems Acquisition Review Council (DSARC) and/or Army Systems Acquisition Review Council (ASARC) reviews. Generically, these reviews are also IPR's.

One of four levels of review are used for key decisions on materiel programs. These four levels are Secretary of Defense, Secretary of the Army/Chief of Staff, Headquarters Department of the Army, and the materiel developer. Decisions by the Secretary of Defense are made on major programs following a DSARC, and those by the Secretary of the Army/Chief of Staff are made on major programs following an ASARC. Programs designated for DSARC review automatically require a prior ASARC review. Major decisions on nonmajor programs are made by an appropriate approval authority following an IPR. The determination as to whether a materiel development program/item/system will be designated major or nonmajor will be made by Headquarters, Department of the Army. Fig. 11-7 shows the management review levels, review designations, and review points during a materiel acquisition cycle. It will be noted that the last three reviews can make use of development and operational test results (Fig. **6-2**).

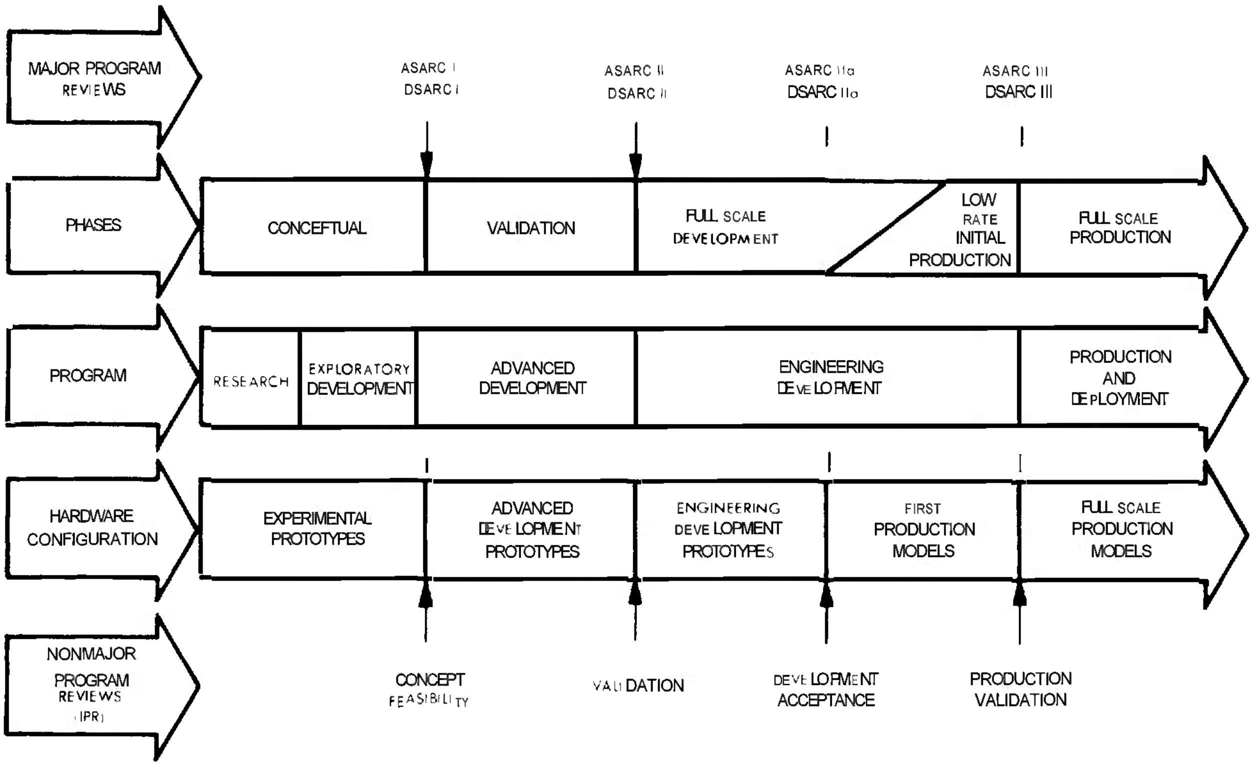


Figure 11-7. Materiel life Cycle Decision Points

The US Army Materiel Command (AMC), as a materiel developer, is granted IPR recommendation approval authority by the Department of the Army for appropriate nonmajor program reviews. This authority may be delegated, when appropriate, to commanders of AMC major subordinate commands, directors of corporate laboratories, and commanders of AMC separate activities by formal letter notification from Headquarters, AMC. The authority to approve IPR recommendations will not be delegated further. AMC commanders/laboratory directors, who have been delegated the authority to appoint IPR chairmen and to approve AMC positions prior to an IPR, may redelegate this authority within their organizations. The authority to approve IPR recommendations, approve the AMC position prior to an IPR, and appoint chairmen will be retained by Headquarters, AMC on designated items/projects.

AMC will provide the chairman for assigned nonmajor IPR's who will be appointed by the appropriate AMC approval authority. The chairman will be the AMC spokesman and will be the final authority at the IPR for decisions concerning AMC. He is authorized to negotiate with other IPR members and to modify the previously approved AMC position when differences occur in order to obtain agreements that will serve the best interests of the Army. The AMC approval authority may appoint one chairman for all IPR's on a project or category of projects (blanket appointment) when, in his judgment, the best interests of the Army in terms of economy of time and money and overall management efficiency are served.

In addition to AMC representation, the IPR team will include representatives from the user, trainer, logistician, and combat developer.

All formal IPR's are scheduled and conducted as conference IPR's. The conference may be cancelled by the chairman when he obtains unconditional concurrences from the other IPR members in the AMC proposed course of action, as indicated in the agenda packages. In the event of comments or nonconcurrences from other IPR members on the AMC proposed course of action, the chairman may cancel the IPR conference provided that he can reconcile their comments or resolve their nonconcurrences to the satisfaction of all IPR members prior to the scheduled conference. When a conference IPR has been cancelled, the chairman will include a justification for the cancellation in his letter to the approval authority which requests approval of the IPR recommendations. The chairman will attach to his letter copies of correspondence from the other IPR members that include statements of their concurrence in the IPR recommendations.

Formal, scheduled IPR's may be supplemented with informal IPR's. An informal IPR may be initiated by the project manager, commander of a major subordinate command, corporate laboratory director, or by Headquarters, AMC, or may be requested by a member agency when there is a need for a review of project status, or a technical problem requires resolution, or for any other valid reason when a formal decision is not required. The IPR may be conducted by correspondence in lieu of a conference provided all members concur. The composition of an informal IPR team is the same as that of a formal IPR team.

DSARC's, ASARC's, and in-process reviews comprise a powerful maintenance management control tool, as well as a powerful management tool for all other disciplines. The formal reviews and resulting decisions establish policy and broad technical guidance that must be implemented. Support subsystem information, requirements, and problems provided as a part of reviews must be complete and accurate. Otherwise, erroneous decisions to the detriment of materiel cost-effectiveness will result. Informal reviews deal essentially in details and should be used to investigate and solve detailed problems that impact the support subsystem.

11-3.7 TYPE CLASSIFICATION

Maintenance engineering management also impacts maintenance management control during system development through participation in equipment type classification actions. As discussed in par. 7-2.5.1, type classification is used to deseribe the degree to which an equipment meets Army requirements. The definitions for type classifications standard (STD) and limited procurement imply that a considerable amount of judgment is involved in the type classification action. There is also the implication that the data used in the judgment can be qualitative as well as quantitative in nature. The phrase "determined to be acceptable for the mission intended and introduction into the inventory" is contained in the type classification STD definition and is a direct result of maintenance engineering management decisions. If these decisions are in error, the consequences will be far reaching, especially in the area of post-deployment costs. Even more serious, the operational readiness of the equipment can suffer degradation. Since the type classification action requires technical (specification), operational, and logistic decisions, care should be exercised to assure that no one system development discipline is allowed to sway the final decision. Consequently, type classification/reclassification actions are controlled by a formal review process. Major system type classifications are approved by the Army Systems Acquisition Review Council, and designated nonmajor systems receive type classification approval by AMC in-process reviews.

11-3.8 COMPUTER AIDED DECISION MAKING

Recent developments in computer design and programming techniques have provided maintenance engineering management with powerful analytical tools to aid in the decision-making process. These tools are valuable to management especially during the system development phase of a program when several support alternatives exist. One of the most versatile of these tools is dynamic simulation.

Dynamic simulation can be used to provide insight into the many complex problems associated with major developmental programs. Unlike most static computer techniques, dynamic simulation does not tell management what to do; however, it provides the intelligence for effective decision making by duplicating the real-life situation within a computer and accumulating all vital statistics experienced as a result of the situation. This technique provides the means for considering all interaction's and interrelationships .among variables without becoming confused by the many details or overlooking significant factors. One of the computer languages used in performing dynamic simulation is called general-purpose system simulation, which basically is an optimization of certain FORTRAN subroutines. A program is constructed by using a set of interrelated logical and mathematical symbols to represent various elemental abstractions, called entities, by which the desired operations can be represented. Through proper sequential use of these entities, entire logistic operations can be simulated.

Seven basic steps are associated with dynamic simulation. These are illustrated in Fig. 11-8. The seven steps, in sequence of execution, are:

a. Problem definition. Here, the basic flow and decision criteria by which the simulation is to be performed must be defined.

b. Logic interpretation. Once the flow and. decision criteria of the simulation have been defined, a logic interpretation is performed to convert the block diagram into the simulator language.

c. Digital conversion. The next step is to transfer the logic flow information to the digital conversion transmittal forms or coding forms. This commonly is referred to as "loading the program".

d. Computer inputs. The transmittal forms are used to prepare punched cards for input to the computer. Care must be taken in preparing the cards; a misspelled word or data in the wrong place will cause the computer to reject the program.

e. Operational simulation. The punched cards are fed into a digital computer. The machine will make all necessary logical decisions in accordance with the flow and decision criteria, keep all records, and perform all required operations.

f. Problem analysis. As a result of the computer simulation, a printout is obtained that defines all significant happenings during the run. This information is provided to management and contains statistical facts, graphs, and curves that reflect what could be expected in the real-life situation.

g. Summary charts (management information). Since the printout contains much residual information, it is common for the programmer to extract the more salient data into summary charts for ease of handling by management.

In the example depicted in Fig. 11-8, the summary chart shows the weeks during which shipments of units of materiel to the depot were made, and the total cumulative shipment for a 9-wk period.

Normally, logistic simulations deal primarily with equipment, people, facilities, cost, and other entities. Simulation often is used to evaluate existing systems. Its real value to maintenance engineering management during system development lies in its capability to reproduce alternative logistic concepts prior to finalizing of the system design. To be a bona fide candidate for a simulation analysis, a logistic problem must be time and event oriented, generally with a degree of complexity arising from alternative decisions based on probability or logic. Typically, a simulation candidate will consist of a number of equipments, with given reliability and maintainability characteristics, which operate and fail in a common scenario, sharing common facilities, parts, and people, and which perform a mission or missions. For example, a scenario may compromise a CONUS depot and supply and transportation systems which support units that are deployed overseas. To track an item through the depot or to trace a single part through the supply pipeline is not an overwhelming task, but to determine—using desktop analysis methods—the overall capability, efficiency, and costs in terms of all equipment which passes through the depot and all supplies which use the transportation pipeline virtually is impossible.

By use of a simulation model, the total support subsystem can be simulated, analyzed, changed, and evaluated rapidly and as often as necessary in order to identify the optimum makeup of the system and the sensitivities of the elements of which it is comprised. Typically, months or years of operation can be simulated in a few. minutes, with the computer providing a time-oriented printed record of output statistics in various formats. These output statistics provide a measure of efficiency and adequacy of the system in terms of utilization of personnel and equipment, queuing, transit times, costs, etc. These data provide the basis for evaluating conceptual candidates or for

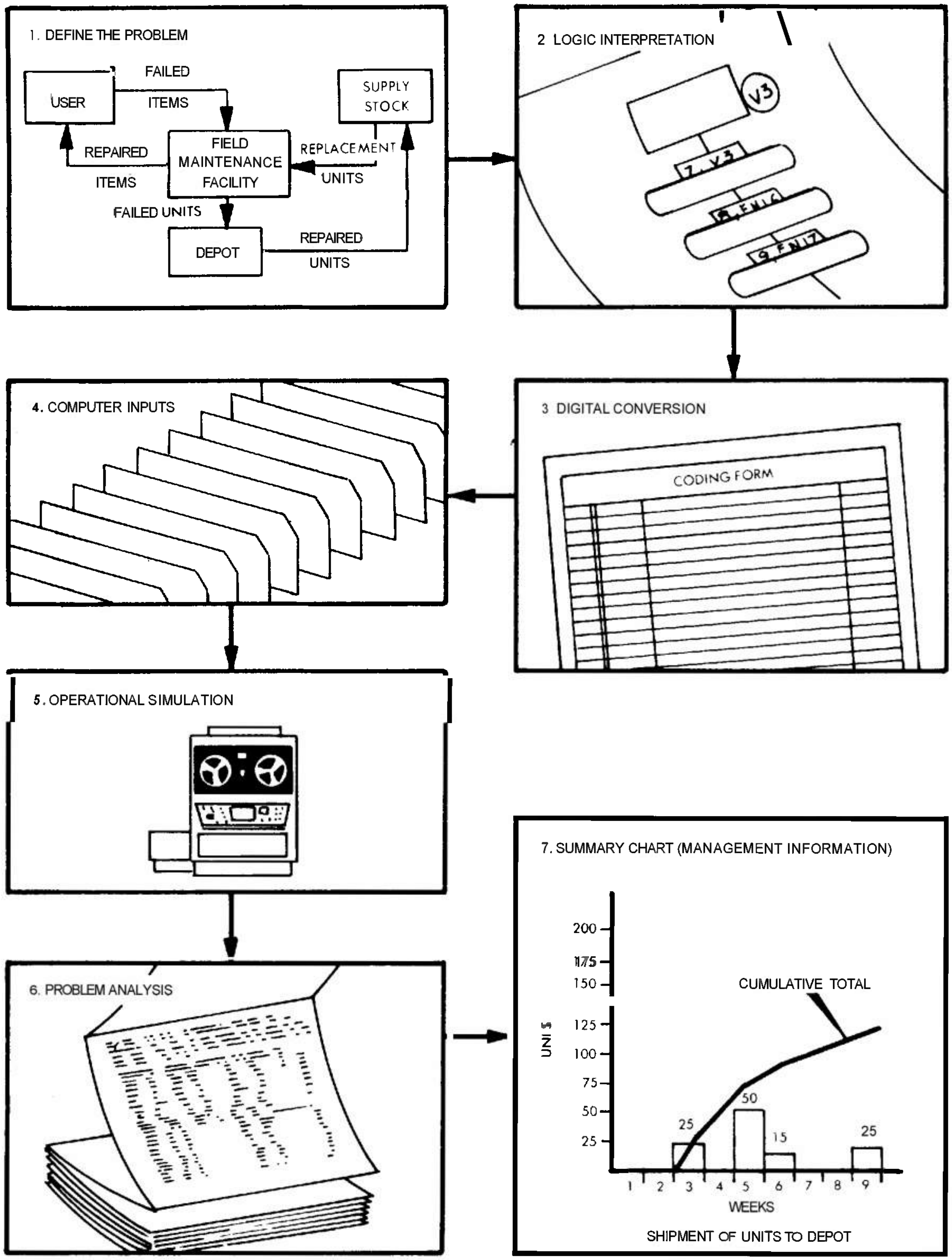


Figure 11-8. Basic Steps in Dynamic Simulation

restructuring a system for more effective operation. If the model has been structured realistically and simulates pertinent aspects of the system, the simulation provides a precise tool to aid in selection of the most cost-effective solution to the logistic problems.

In summary, simulation is a tool that can provide rapid answers to complex questions. Simulation is to maintenance engineering management what a calculation is to the statistician or a slide rule is to the design engineer. Unlike many computer techniques, simulation does not make decisions for management. However, it does allow management to answer such questions as "What would happen if . . .?" or "Why not try doing it this way?". Finally, with simulation, strategy can be planned before a problem arises. This capability provides management with the time and background data needed to make intelligent decisions.

11-4 MAINTENANCE MANAGEMENT IN PRODUCTION MAINTENANCE

The term production maintenance is synonymous with depot maintenance. This level of maintenance is discussed in Chapter 10. The discussion that follows will address the maintenance management aspect of production maintenance as it relates to maintenance planning, programming, budgeting, funding, supply control, production control, and maintenance engineering.

Depot maintenance is the responsibility of and is performed by designated maintenance activities (including contractor facilities) to augment stocks of serviceable materiel by overhauling and rebuilding unserviceable assets that require maintenance beyond the capabilities of general support activities. This responsibility is satisfied through a combination of more extensive shop facilities, more specialized equipment, and more highly skilled personnel than those existing at lower levels of maintenance. Depot maintenance usually is accomplished in fixed shops and facilities that are Government-owned and -operated, Government-owned and contractor-operated, or contractor-owned and -operated.

Depot maintenance support demands that four essential elements must be available within the same time frame. These elements are:

a. Unserviceable but repairable items

b. Parts required to accomplish the repair

c. Obligational authority

d. Repair capability, including documentation, tools, test equipment, plant facilities, and manpower allocations.

The process of bringing these essentials together requires considerable coordination among individual commodity commands, the AMC, the Department of the Army, other CONUS agencies, and oversea commands. A focal point for this coordination is the United States Army Major Item Data Agency (MIDA) through its Central Workloading Activity (CWA) and Depot Maintenance Data Bank (DMDB) functions. MIDA serves as the interface between the item manager (a commodity command, oversea command, project manager, separate installation or activity reporting to Hq. AMC or the CWA, and responsible for generating maintenance requirements), the depots, and other agencies.

11-4.1 GENERAL PROCEDURES (Ref. 13)

The procedures that follow govern the general activities of the CWA, item managers, etc., and the use of the DMDB in the management of production maintenance:

a. Each item manager will be responsible for determining his depot level materiel maintenance requirements and developing appropriate maintenance support service program requirements for the current year and each applicable planning year. These will be submitted for inclusion in DMDB records.

b. Data for organic, contract, and/or interservice depot level maintenance effort for each requirement will be forwarded to the DMDB and will be updated concurrently. Following initial program establishment in the DMDB files, all data element exchanges will be on an exception basis, containing only those data elements which change information in the recipient's files.

c. All requests for maintenance from customers outside the Department of the Army will be processed as prescribed by applicable AMC regulations. Depots will not negotiate for this type of work. All requests for intra-Army depot level maintenance will be processed through the applicable maintenance interservice support office. All accepted proposals will be workloaded to the selected primary or secondary depot by the CWA.

d. Each commodity command will be responsible for keeping the CWA updated by mailing copies of all depot maintenance interservice agreements, international logistic programs, foreign military sales, or other depot maintenance agreements for other than Army customers which have been identified for depot maintenance.

e. Each item manager will establish and maintain a nonduplicative commodity command level of sequence of priorities for all organic depot level maintenance programs initiated by the command. This may include assigning different priority sequence numbers to portions of a total quantity on one requirement record. The CWA using the DMDB will assign work and commit depot level resources in accordance with priority sequence and resource availability with an automatic consideration of cost-effectiveness. Organic maintenance facilities will establish shop schedules in accordance with priority sequence and resource availability.

f. Upon determination of the commodity command depot maintenance requirement, the item manager will take action to assure availability of required unserviceable assets. Weekly, each commodity command will prepare and forward to the DMDB increases and decreases in the on-hand availability of unserviceable assets for each program, by depot. The CWA using the DMDB files will assign work to organic maintenance shops on the basis of the asset information from commodity commands and others. If actual availability does not agree with that reported by the commodity command, the depot supply activity will initiate action with the commodity command to reconcile inventory records, after which the command will advise the CWA of any desired change in instructions.

g. Primary and secondary depots will be designated by the commodity commands with Hq., AMC, approval after full coordination with the CWA and the U S Army Maintenance Management Center. Primary and secondary depots will be assigned initially for each weapon/support system on the basis of lowest time/overhaul cost of the system and other significantly defined factors. After initial designation, assignments will be reviewed annually for cost-effectiveness.

h. The commodity command will assure that the unit maintenance total cost transmitted to the CWA on the maintenance requirement record is the cost approved by the command after allowable maintenance expenditure limits have been considered. At the depot maintenance activity level, materiel classified as "unserviceable, economically repairable" by quality assurance personnel will be accepted as economically repairable except for hidden defects which can be determined only after teardown. Detection of such hidden defects during maintenance will be referred immediately to the quality assurance activity for possible reclassification. Documentation of the facts will be maintained in the record folder of the depot maintenance activity and will be reported to the DMDB. The CWA will approve the cost adjustment or refer it to the commodity command for decision in accordance with established dollar and quantity tolerances.

i. The CWA using the DMDB will prepare ADP programs to produce maintenance management information in the format and frequency required by the Director of Maintenance, Hq., AMC.

j. The CWA will not request a depot maintenance activity to negotiate for, let, or administer national maintenance contracts. The Depot Production Planning and Control System will assure that depots are not able to negotiate and administer contracts for complete maintenance programs. This policy requires the depots either to accomplish the major tasks as assigned or to report back to the CWA their organic inability to accomplish the task in the time frame established. The CWA then will reassign the work to another depot or report the status to the commodity command which then can negotiate a national contract. Depots will be authorized to issue supportive service contracts only as a supplement to their capability in order to perform a portion of the task and as an aid in handling emergencies.

k. The Director of Maintenance and the Comptroller, **Hq.,** AMC, and the commander of each commodity command will provide the

CWA with current program and budget guidance and with manpower guidance to be used in determining maintenance net capacity quantities for the execution year and the 5 planning years.

l. All progress and cost status reporting from the organic depot maintenance activities will be transmitted directly and exclusively to the DMDB. Contractual progress and cost status reporting will be provided to the DMDB from the commodity commands. The DMDB will provide for expeditious forwarding of these data to the appropriate recipients.

m. The CWA using the DMDB will treat workloading, capability data, reporting data, etc., by depot; however, under depot complexing, the DMDB will deal with the complex command service center only. Data transmission and communication will be with the complex command, service center and not with its associated depot maintenance activities.

n. The Organic Depot Maintenance Production, Planning, and Control System will provide for consolidation of like items on depot production schedules. A single program control number will be assigned to collect labor and production, as well as for repair part forecasting and requisitioning actions. The system will provide for proration of cost data to the originating order no more frequently than daily, but no less frequently than the 15th and end of each month.

o. The decision and action on final job order closeout and billing are the responsibility of the comptroller. Maintenance will be allowed 15 days after final production to close out records. After that period, the comptroller will insure that all outstanding financial transactions have been completed and will take expeditious action to assure closeout by the 15th of the month following that in which the specific job or service order is completed.

p. Depot maintenance consumption data will be submitted by every depot level materiel maintenance activity–including oversea, commercial, and cross-service contracts–on those programs from which the item manager required reporting. Both Government-furnished parts and contractor-furnished parts consumed will be reported. The data will be reported directly to the appropriate commodity command.

q. Consumption data will be maintained by the end item commodity command for all repairables under its management subject to depot maintenance. The data will be used in maintaining current depot maintenance part requirement lists (DMPRL's).

r. Repair part and special tool lists (RPSTL's) and DMPRL's developed and maintained by the end item commodity command will portray repair part requirements for planned and scheduled depot maintenance programs. Upon request, the end item commodity command will provide an RPSTL/DMPRL to each primary or secondary depot.

11-4.2 REQUIREMENT INPUTS (Ref. 13)

Item managers are required to report depot materiel and maintenance support requirements to the DMDB. The procedures that follow govern this reporting and associated activities:

a. All orders placed on depot maintenance activities–regardless of source or customer–will be controlled through the Central Workloading Activity (CWA), except for technical and delivery phases of negotiation with interservice customers. Requirement data also will be submitted to the DMDB for all depot level maintenance programs placed on contract by the commodity commands and oversea commands, regardless of funding.

b. Requirements will be specific, both to the work encompassed by the order and order terms, and will include necessary special instructions of either an administrative or technical nature. For example, the authorization for overtime (premium) to be worked involving additional funds must be provided by the item manager.

c. The procurement of repair parts necessary to support materiel requirements will be based on the Army materiel plan developed by the DMDB. Procurement action will be initiated sufficiently in advance of the execution year to allow for leadtime, etc. and to insure delivery to the performing activity at least 90 days prior to the date the item is introduced into the maintenance shop. The quantities of procured items will be sufficient to support schedules for at least one-quarter of the the fiscal year. This action taken by the supply manager will include all repair parts required, regardless of the item manager or class manager having inventory control of the parts.

d. Coordination between commodity commands is the responsibility of each supply manager accountable for the basic item, component, or accessory. This also includes coordination with the counterpart in other Government agencies.

e. Supply managers continually will review materiel requirements with status reports provided by the DMDB to assure that parts support is in consonance with schedules reported by the performing activity. If the supply manager cannot obtain the parts required, the maintenance programmed quantity total will be reduced in order that a lower priority materiel requirement may be workloaded.

f. The item manager will report to the DMDB, by stock number, those repair parts and components which are in long supply or excess and which will be requisitioned from the supply system for use in overhaul. The repair of listed parts/components during overhaul may not be accomplished without prior authorization of the responsible commodity command.

g. Performing activities are responsible for assuring that the, status of asset availability data reported by them to commodity commands is current and accurate. Timely release of operation and maintenance, Army funds by the CWA to Army industrial fund depot activities is dependent upon accurate and current asset balances in the DMDB.

h. Action will be taken by the item manager to expedite turn-ins of unserviceable repairable assets. If the field does not react to expediting actions by the commodity command, the problem will be referred to Hq., **AMC,** for appropriate action.

i. Item managers will coordinate with the National Maintenance Points to insure that maintenance standards/technical packages (depot maintenance reference lists (DMRL's) and depot maintenance work requirements (DMWR's)) are made available to performing activities prior to or concurrent with input of the requirement to the DMDB. Absence of standards/technical package identification will require coordination between the CWA and the commodity command.

j. When a gross maintenance requirement becomes known for a current year or for any of the 5 projected years, that requirement will be input by the item manager to the DMDB. To accommodate the required input of depot materiel maintenance data for that materiel not the responsibility of the commodity command but accomplished by AMC depot maintenance resources and facilities, the item manager's role will be assumed by the CWA acting as the coordinating representative.

11-4.3 WORK ORDERS AND REPORTS (Ref. 13)

The CWA plans, schedules, and orders the work for the AMC depot level materiel maintenance effort. In the accomplishment of these functions, a linear programming model is used to develop a balanced workload for each year, including the current year. This is an iterative process accomplished in conjunction with the depots. Based on the balanced workload, work orders are issued to the depots for acceptance, rejection, or negotiation. Par. 10-3.2.1 describes work order processing.

Among the reports submitted by the depots after the acceptance of the work orders are those pertaining to production status, cost, and repair part consumption. Information in these reports coupled with information on repairable asset availability provided by appropriate agencies comprise the basic data required for management of the current year depot maintenance program.

11-4.4 CONTROL OF DEPOT EXPENDITURES

Control of depot expenditures is essential if the Army depot mission of achieving a maximum operational readiness posture at minimum cost is to be realized. The large quantities of materiel now in the Army inventory—and their complexity, cost of acquisition, and maintenance—generate a continuing demand for resources. These resources—fund allocations, manpower, materials, facilities, and tooling—are associated directly with the operational cost factor. Greater management emphasis is necessary to obtain the optimum return for each cost dollar if the cost factor and operational efficiency are to reflect the desired relationship.

Management objectives that are common to both the effective and economical development of the maintenance effort and the use of resources should be established as an integral part of depot maintenance operations. In this way, both materiel readiness and cost control endeavors are influenced. Specific purposes of management objectives of this type are:

a. To maintain materiel, using available resources to the maximum extent, in a manner that enhances its readiness posture and its ability to perform designated functions efficiently and safely

b. To stimulate and assist in the ready flow and exchange of maintenance experience, techniques, processes, and data among maintenance shops, maintenance personnel, and appropriate field organizations

c. To increase the general understanding of the importance and magnitude of effectively maintaining modern materiel, and the need for improved maintenance discipline

d. To provide appropriate assignment of maintenance activities as a prerequisite to effective and efficient maintenance

e. To encourage the standardization of maintenance activities, procedures, and use of maintenance data and reporting.

Basic objectives stress economy of operation and the accomplishment of maintenance at the lowest possible cost. Closely associated with economy is the usually austere availability of fund allocations, which determine, over an extended period of time, the size of the depot work force and the breadth of the workload. Maintenance managers should establish management policies that complement management objectives. These management policies provide for:

a. Establishment of uniform criteria and standards which prescribe the procedures for economical repair, overhaul, and rebuild of applicable materiel

b. Determination that repair and overhaul of unserviceables are compatible with supply system requirements and disposal criteria

c. Consolidation of depot maintenance shops and facilities to the maximum extent feasible

d. Vitalization of depot training programs, and career development of technically qualified personnel for assignment to maintenance management positions

e. Establishment of internal depot procedures for accurate identification of maintenance costs and their correlation to support operating activities

f. Development of uniform criteria and procedures for computing maintenance workloads and backlogs.

The source documents for collecting elements-of-cost data for depot maintenance operations or for activities performing depot maintenance operations provide the basic accounting requirements for recording, controlling, and reporting the costs incurred. The basic documents used for this purpose are:

a. Cost distribution journals, which identify separately all labor, materials, supplies, contractual services, and other expenses

b. Cost ledgers, used for recording and summarizing detailed cost data by cost account and elements of cost such as direct man-hours and work units completed

c. Job order cost sheets, which are established for each work order received by the depot or activity.

Each activity performing depot-type maintenance is allowed considerable latitude in the development of effective and economical methods and procedures which are consistent with basic accounting requirements but which are adaptable to the organization and accounting requirements of the activity.

The basic source for collecting and recording the labor effort is either the daily activity sheet or the individual time cards, both of which report man-hours of labor by cost code or job order number. Upon reconciliation with attendance records, the man-hour information is forwarded to cost accounting, where total man-hours by cost codes or job order numbers are posted. In costing out total man-hours, either actual or average departmental rates can be applied, depending upon the size of the shop and the work force involved.

11-4.5 ESTIMATING MAINTENANCE TIME (Ref. 3)

Production maintenance time estimates generally are obtained from a combination of historical, statistical, and engineered standards. Historical standards are obtained from past records of the actual time and cost involved in completing a specific overhaul operation. Historical standards may be derived from the actual time and cost to overhaul one unserviceable item, or it may be computed from an average of the time and cost to overhaul a quantity of like unserviceable items. Historical standards are not particularly accurate for scheduling and control purposes because the type of and extent of repairs required to restore unserviceable items vary with individual items. However, the broader the overhaul experience has been with an item, the wider the base from which the average may be computed; consequently, the production standard derived will be more accurate than would be possible if this condition did not exist. A statistical standard is similar to a historical standard in that it is derived by averaging actual recorded time or cost figures for a specific operation. It, too, is based on historical data, but, in addition, it considers data on operations and costs which depart significantly from the norm. In statistical standards, both superior and poor performances are excluded. The statistical standard, therefore, is more a median than an average and is felt to be more accurate than historical data alone. Actually, a combination of the two methods frequently is used in production control practices.

Because historical and statistical standards are based on past performance, and thus may embody production inefficiencies, engineered time standards have been developed. Three methods for determining engineered time standards are:

a. Motion-time Analysis. In a motion-time analysis, the job to be analyzed first is broken down into simple body movements such as lift, move, turn, and grasp. Generally, for relatively short operations, a more detailed breakdown is required, and the subsequent computations are more complex than is the case for longer jobs. Once a job has been broken down into its various parts, the analyst refers to special tables that contain standard times for each body motion, taking into account the distance the particular body member moved and other factors such as the resistance met or the care required. By totaling times for all the movements, the analyst is able to develop a standard time for the whole operation. Adjustments for worker proficiency are unnecessary because the table factors themselves reflect the motion times of a normal worker. Fatigue allowances must be considered, however, along with other pertinent job factors.

b. Stopwatch Time Study. In a stopwatch time study, the job to be evaluated is broken down first into basic elements or timing points. After this division of the operation, the analyst then observes several complete cycles of the operation, recording the time taken by the operator to perform each element. Then, the average time for each element is computed. The analyst adjusts the average time to compensate for a slow worker or for a worker who is working at too great a speed. After performing this adjustment, the analyst develops the standard time for the whole operation. Consideration is given to other factors such as fatigue allowances, procurement of necessary tools and parts, authorized breaks, and cleanup time. The result is an engineered time standard for the operation.

c. Work Sampling. Both of the foregoing time study methods are suited best to repetitive jobs such as those which typify most production line operations. AFM 25-5 (Ref. **14)** describes a work sampling time study method that has more general application. The method is based on the principle that a sufficient number of samples taken at random from a large group tends to exhibit the same charactersitics of distribution as the entire group. Conclusions are drawn about the whole population or universe based on a limited number of samples. At random intervals, the workers are observed, and the state or condition of each worker's activity is noted and classified into predetermined categories.

Application of the method involves the determination of the man-hour population from which samples are taken; the designation of the time categories into which the samples are plated; making the actual observations, including periodic performance rating; computation of the percentage of time spent on each category (ratio of the total samples in any one category to the total samples taken); and, finally, application of these percentages to the total man-hours sampled to determine the time spent on each designated category. AFM 25-5 provides procedures for accomplishing all of these activities.

11-4.6 SCHEDULING

A major aspect of production that management must consider both before and during actual maintenance operations is whether or not production schedules provide for the economical and efficient use of all available production resources such as facilities, manpower, equipment, and materials. Adequate production scheduling for maintenance operations is the first essential step in securing successful production performance, and proper use of these resources virtually assures the success of the production scheduling operation. Production scheduling encompasses the following planning actions:

u. Determining the production resources—funds, economically repairable and unserviceables, repair parts, labor, tools, materials, and machinery—required for a specific maintenance program

b. Establishing production procedures that insure the successful accomplishment of the depot maintenance program

c. Formulating detailed standing operating procedures for all aspects of the work to be performed

d. Differentiating between procedures for production runs and those for the occasional odd job.

From a maintenance management point of view, maintenance scheduling has much the same relation to programming as programming has to long-range planning. A program is intended to implement a plan, and a schedule is intended to outline the specific means by which the more immediate objectives of the program can be accomplished. A definite dividing line cannot be drawn between programming and scheduling, for scheduling is merely a continuation of the programming process. The broad objective of the maintenance scheduling function is the same as that of the maintenance programming and budgeting function. This objective is to obtain from available maintenance resources the most effective performances and use possible by formulating timetables and procedures for accomplishing a required workload. Unlike programming, however, scheduling deals in specifics; i.e., specific installations, definitive workloads, and definite time periods.

When scheduling workloads, the basic factors considered are the types and number of items to be repaired or overhauled, the activities at which the program will be accomplished, the number of items each activity will be assigned, and the time frame in which the program will begin and end.

The depot commander to whom a workload has been assigned is responsible both for devising internal production schedules and work orders that delineate the methods and procedures to be followed and computing the resources necessary to process the assigned workload. This phase of maintenance scheduling is directed toward the coordination of resources such as labor, repair parts, funds, and facilities to accomplish the assigned workload in the most effective manner and within allotted time frames.

11-4.7 WORK PRIORITY

Work priority plays a part in production maintenance management. In the scheduling and execution process, the order of overhaul depends upon the relative importance of an item to the Army and the immediate availability of required unserviceable assets. From the time operating programs are formulated to the time they are implemented, a never-ceasing evaluation and reevaluation of them are carried out at every level of command. Some overhaul projects, such as those for strategically important international logistic program shipments, often are assigned top priorities by the Department of the Army at the direction of the President or the Secretary of Defense. Other programs may be given a priority status by the CWA as a result of depleted stocks or increased demands. The depot commanders usually schedule repair-and-return-to-stock items on established policy and operating procedures.

11-4.8 MAINTENANCE STANDARDS (Ref. 3)

It is Army policy that practical and measurable standards be developed for each major item of materiel. The primary purpose of these standards is to provide meaningful data by which the readiness posture can be measured or ascertained and a predictable level of reliability insured. Further, it is policy that these standards be simple enough to be used by unit personnel as well as by personnel of inspecting agencies.

In keeping with the requirement to establish measurable standards as a means of improving the readiness status of equipment, Army agencies have developed performance standards; serviceability standards; maintenance standards, including overhaul standards; equipment serviceability criteria; and operationally ready standards. By definition, a standard is an established or accepted rule, measure, or model by which the degree of satisfactoriness of similar items is determined. Four types of standards are of concern to production maintenance management: performance standards, serviceability standards, maintenance standards, and equipment serviceability criteria. Definitions of these standards follow:

a. Performance Standard. Generally, the term "performance standard" refers to an established number of man-hours required to perform a unit of work. In terms of maintenance, however, it may refer to performance measures relative to the number of satisfactory hours of operation, the number of pounds of pressure, or the amount of stress or strain to which materiel can be subjected before a breakdown occurs or maintenance is required.

b. Serviceability Standard. A serviceability standard is a measure which specifies the operating limits for an item. When these limits have not been reached, the item is considered to be serviceable and safe, but when these limits have been exceeded, the item is considered to be unserviceable. Serviceability standards involve a consideration of wear limits, deterioration, performance as an indication of the degree of serviceability, and damage that affects the serviceability of equipment.

c. Maintenance Standard. A maintenance standard is a measure which specifies the minimum condition to which an item must be restored by repair, overhaul, or some other maintenance function to insure its satisfactory performance for a specified period of service.

d. Equipment Serviceability Criteria. Equipment serviceability criteria are standards used to measure the combat readiness status of equipment. A color code or "traffic light" concept is used to designate the degree to which equipment probably will perform its combat mission. According to the "traffic light" concept, the color code green is assigned to equipment which can be expected to perform its primary mission for a sustained period of operation of approximately 90 days, providing normal maintenance is performed. The color code amber is assigned to equipment which will move, shoot, communicate, or otherwise perform its combat mission, but which is not operationally reliable to the same degree as equipment that is coded green. In other words, amber-coded equipment cannot be depended upon to operate efficiently for a sustained period of 90 days because of shortcomings or other conditions, such as wear, which cause marginal classifications. The color code red is assigned to equipment which cannot perform its combat mission because of deficiencies such as those which evolve from a combination of wear factors or result from failure to reflect the application of an urgent modification work order.

11-4.9 WORK MEASUREMENTS

The results of work measurement data are accumulated at the production maintenance activity and promulgated to the higher commands through various reports. Some reports are cost-oriented, while others deal with the quantity of work accomplished. Most of the reports are generated by the production control operation of the production maintenance facility. This function develops both internally and externally distributed management information. The internal reports enhance efficiency of in-house operations, and the external reports provide upper levels of Department of Defense, Department of the Army, and AMC management visibility into the utilization of resources and effectiveness of production maintenance operations. As shown in Fig. 11-9, external reporting uses exception-type reports from the maintenance program operations management level upward. These reports are derived from the detailed data submitted from maintenance operations level

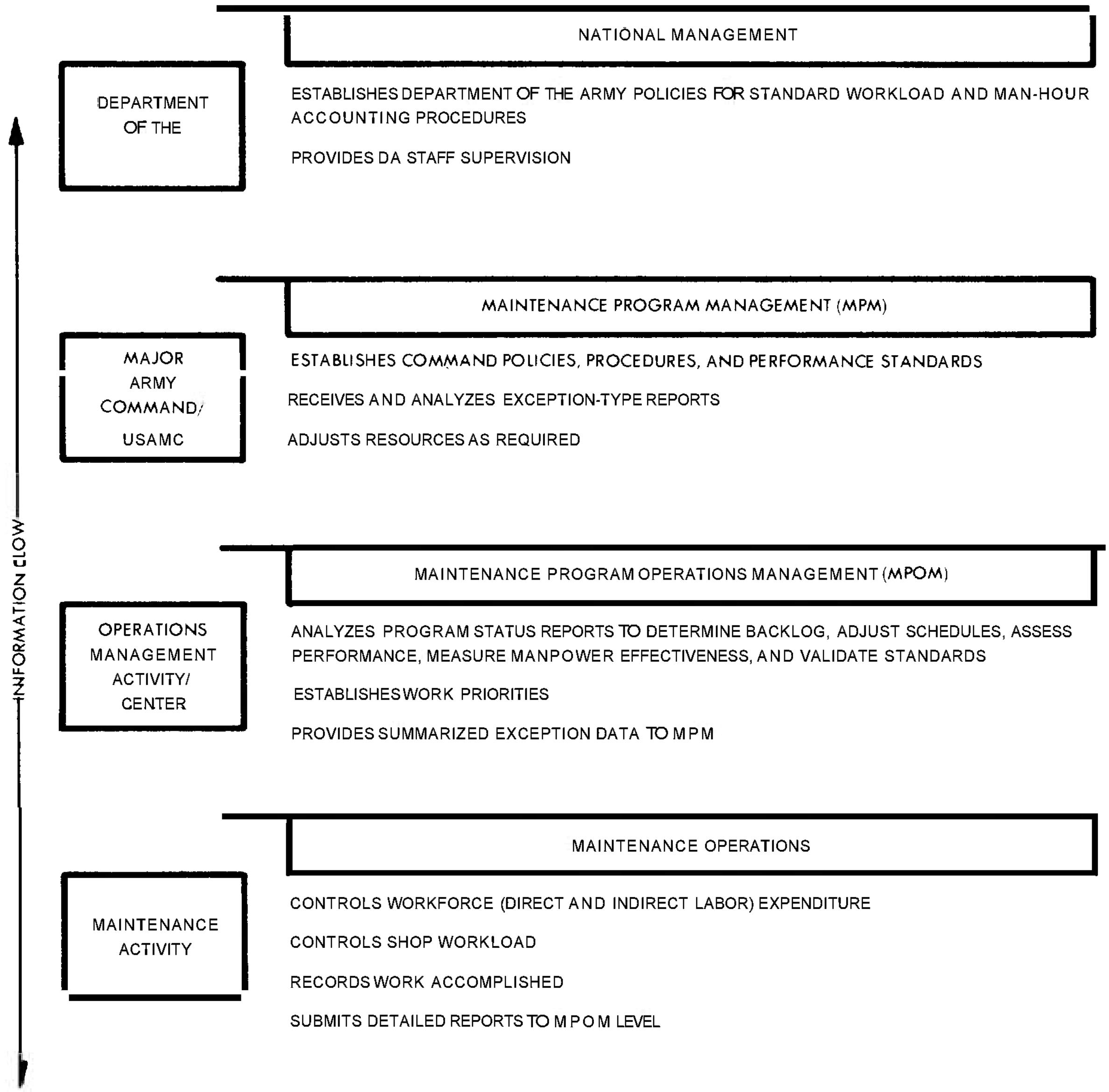


Figure 11-9. Workload Accounting and Manpower Management (Ref. 2)

management. Also, the depot reports into the Army Industrial Fund/Expense Appropriation Management (AIF/EAM) files through a work measurement program.

11-4.10 PRODUCTION LINE STOPPAGES

Production line stoppages have far-reaching effects on maintenance management of Army materiel. The most obvious and immediate effect is that manpower and production facilities that are subjected to elaborate scheduling operations face the possibility of idleness. This, of course, inevitably decreases efficiency and increases costs. More serious, however, is the fact that materiel readiness can be affected. As discussed earlier in this chapter, equipment is scheduled into production maintenance facilities on the basis of relative importance of the equipment to the Army mission.

Maintenance management must respond rapidly to production line stoppages. Once the stoppage cause has been analyzed thoroughly, decision questions must be answered. Typical of these questions are: Can the process flow be rerouted? How many work centers will be affected? Is rescheduling action required? Should production be delayed at all work centers or only at the work center directly affected?

The most prevalent cause of production line stoppages is unavailability of repair parts. This will be discussed in greater detail later in this chapter, but is mentioned here as it applies to management reporting of line stoppages. The responsibility for reporting these stoppages rests with the installation supply accounting activity. Prior to advising the installation supply accounting activity that a production line stoppage exists, the parts management activity must have taken the following actions:

a. Determine that local manufacture/fabrication, local procurement, or cannibalization is not practical.

b. Determine that the supply system has not responded satisfactorily.

c. Determine that prior action had been taken to upgrade the requisition, for the production line stoppage in question, by the installation supply accounting activity.

Reporting of production line stoppage is accomplished in accordance with current AMC regulations, and these reports provide management visibility into this critical aspect of production management.

11-4.11 WORK STOPPAGE PREVENTION

One of the key functions of production maintenance is to predict work stoppages and prevent them from occurring. Generally, stoppages occur for three major reasons: lack of assets, lack of parts, and/or lack of resources. These subjects are discussed in the paragraphs that follow, along with a scheduling model that alerts management to potential work stoppages.

11-4.11.1 Availability of Assets

Lack of assets usually occurs because repairables are not being generated (are not failing) at the expected rate. Asset shortages also can be experienced when the accountable stock records at the National Inventory Control Point do not reflect the true depot stock balance. The program may be authorized and the stock records may reflect asset availability, but the depot maintenance activity has received notification that assets requested to be moved from the storage location to maintenance are not available. In this case, depot procedures should be established to insure that appropriate actions are taken by the depot supply and transportation activity to correct the asset balance through the stock status reporting system of the depot maintenance production planning and control system.

11-4.11.2 Availability of Parts

Parts management is a vital aspect of production maintenance management. Its ultimate objective is to insure that adequate quantities of the right types of repair parts are available to meet production requirements at a particular maintenance activity. Proper parts management can mean the difference between efficient or inefficient repair or overhaul operations, economical or costly production, timely or delayed completion of scheduled work, and a high degree of equipment operability or an excessive amount of deadlined equipment. The maintenance function should be accomplished with a minimum investment in repair parts; otherwise, fewer funds will be available for other depot repair programs. Stocks of repair parts must be kept at minimum levels in order to reduce attendant "holding costs"; i.e., the costs to store, inventory, inspect, preserve, maintain records, and dispose of excess and obsolete stocks. Yet, most important, repair parts must be available as scheduled to avoid line stoppages. Avoiding this type of stoppage depends to a great extent on accurate forecasting of requirements.

Parts forecasting is one of the most important elements of the depot parts management effort, for the accuracy of parts requirement forecasts often determines the effectiveness of production scheduling. The requirements for overhaul may be relatively predictable and therefore controllable, but forecasting repair part requirements without a complete teardown and inspection of the item to be overhauled is difficult and often impossible. The age of an item, the environment in which it has been used, its operator, and a number of other variables combine to make the usage history of each item entering the depot maintenance shop unique. As a result of these variables, two items of the same make and model may have quite different requirements.

The process of forecasting and the subsequent procurement of parts for the repair of moderate- and high-density end items begin with the initiation of a work order issued by the CWA. After initial preparation or review by the Production Control Element of the Depot Directorate for Maintenance, the order is sent to that maintenance element of the Maintenance Directorate which is responsible for determining parts requirements. This element computes the kinds and quantities of parts necessary to perform the work, whether it be a relatively small job likely to require only one or two days or a production line run scheduled to operate for a number of months. The information for these computations generally is taken from the mortality data file. This file contains historical data on parts usage and other repair operations of the past. Of most significance are the consumption or mortality rates which indicate the quantity of a part that was used in overhauling 100 end items.

As previously mentioned, work stoppages due to lack of repair parts are reported into the Army depot maintenance production and control system, which produces a parts shortage report. This management report is issued to parts managers on a weekly basis. It reflects the quantity of each stock item number that is in a shortage status.

With the report, the parts manager will identify which of the parts that are in a shortage status are line-stoppers and potential line-stoppers, and will annotate the report manually to reflect this status and hand-carry it to the installation supply accounting activity on a weekly basis. The installation supply accounting activity will take appropriate action to upgrade the requisition in accordance with existing supply procedures.

11-4.11.3 Availability of Resources

Production maintenance managers cannot manage resources efficiently if the various costs of operation are not known. Appropriation accounting at the depot level can provide such information. The extension of the Army industrial fund and funding practices to depots enables managers to acquire cost accounting data for practically any element of expense desired. Funds may be obligated and expended for resources during one accounting period, while the costs to which these funds apply may have been incurred in an earlier accounting period. Funds must be obligated during the year of appropriation, but they can be expended during a later period, not exceeding two additional years. To manage effectively, the depot commander and his managers must have definite information available so that the current cost of operations is known.

A comprehensive cost accounting system is provided by the Department of the Army. This system applies worldwide to all depots, installations, and activities performing depot maintenance operations. The objective of this cost accounting system is to:

a. Provide management with data to measure cost-effectiveness.

b. Provide the basis for determining budget program quantities and the total maintenance cost of end products produced and services rendered.

c. Account for all elements of costs incurred in the performance of depot maintenance, including indirect maintenance expenses, general and administrative expenses, and maintenance support expenses, regardless of how such costs are financed.

d. Record costs by identifying the functional organization that incurs the cost or performs the work.

e. Provide data to assist in performing comparative cost analyses for two or more depots, and for in-house and contract maintenance operations relative to the same or similar overhaul programs.

f. Facilitate interservice support to obtain the most economical use of facilities.

g. Properly classify and accumulate various depot-generated maintenance data required for preparation of the Army depot maintenance cost summary and other related reports.

At the local level, the cost accounting system is augmented by internal depot data sources that provide basic data for cost analysis. Analysis of costs is a management technique used to reveal data and information that can lead to methods for improving efficiency. As a part of this technique, data relative to resources such as the costs of all labor, supplies, and services used by the depot activities during a particular accounting period are recorded, and all direct and indirect costs are collected under various account titles. At the end of a specific period, a summary operating statement of costs incurred by the various shops is prepared. Depots collect, record, and report shop costs by individual job orders for internal depot use. The actual job order costs, as well as total costs reported on the shop operating statement, are compared with budgeted or forecast costs. At the end of a fiscal year, the operating statements for all accounting periods in the fiscal year can be used, with appropriate adjustments, to forecast future fund requirements.

Cost analysis is an essential element in the management of production resources. Constant comparison with forecast resource requirements can aid maintenance management decision-makers in their efforts to predict and prevent work stoppages.

11-4.11.4 Shop Scheduling Model

The Army production planning and control system includes analytical tools to assist in prediction and control of production line stoppages. One of these tools is a shop scheduling simulation model, which functions as described in the following paragraphs:

a. Orders issued by the Major Item Data Agency are costed and accepted automatically, or are marked up when within established parameters. Orders outside the parameters are directed to production controllers for action within prescribed time frames. Each order reflects its priority and required delivery schedule. Subsequent to acceptance, each order is stored within the automatic data processing equipment in the priority sequence in which it is to be accomplished.

b. Ninety days prior to induction of assets, the scheduling model begins simulating the flow of work through the shop work centers. The simulation continues until actual movement of materiel from storage to maintenance takes place. Upon receipt of materiel at the work center, the supervisor creates automatic data processing inputs.

c. Production flow begins with acceptance of materiel by the supervisor of the first work center. The automatic data processing inputs created by supervisors provide the data required by the scheduling model to continue scheduling simulation with actual experience data. Production progress information is provided to the scheduling model through daily inputs. Labor hours expended against each job order are compared with man-hour standards and reported production codes to identify potential overproduction/underproduction problems and the impact on subsequent work centers. The scheduling model is dependent largely upon realistic man-hour standards. Each planning and production control activity, in conjunction with depot maintenance engineers, constantly reviews man-hour standards to prevent overstating or understating of man-hour requirements in the automatic data processing files. Weekly, work center supervisors receive work schedules that depict the daily work center schedule of inductions and production output for the subsequent 2-wk period. The labor and production inputs identify whether or not the inductions and production are in consonance with the overall schedule. Each work center makes its contribution to the overall maintenance effort. In this connection, a production slippage in one work center will cause the scheduling model to compensate for the production slippage by rescheduling other work into subsequent work centers.

In summary, the scheduling model provides an automated scheduling system to accomplish the following objectives:

a. Simulate program execution based on projected workload requirements versus available manpower resources prior to the actual execution phase.

b. Identify potential manpower/scheduling problems.

c. Allocate work center resources based on Major Item Data Agency assigned priority, required completion date, and current status of each individual job order (number of days ahead or behind schedule).

d. Develop a 2-wk daily schedule for each work center.

REFERENCES

1. DoD Inst. 4151.12, *Policies Governing Maintenance Engineering Within the Department of Defense,* 19 June 1968.
2. *Standard Army Logistic System Maintenance Reporting and Management Guidance and Reporting System, General Functional Description,* U S Army Logistic Doctrine Systems and Readiness Agency, July 1971.
3. FM 38-5, *Logistics Maintenance Management,* May 1969.
4. TM 38-710, *Integrated Logistic Support Implementation Guide for DoD Systems and Equipment,* March 1972.
5. *Support Model Reference List,* U S Army Maintenance Management Center, December 1973.
6. DA PAM 700-21, *Army Test, Measurement and Diagnostic Equipment Register Index and Instructions,* December 1973.
7. MIL-STD-1388-1, *Logistic Support Analysis,* October 1973.
8. DoD Dir. 4100.35, *Development of Integrated Logistic Support for Systems/Equipment,* 1 October 1970.
9. AMCP 706-134, Engineering Design Handbook, *Maintainability Guide for Design.*
10. *Army Force Planning Cost Handbook,* Comptroller of the Army, July 1973.
11. AMCR 70-5, *Program Reviews for Milestone Decisions During Materiel Acquisition,* 14 September 1973.
12. DA Pamphlet 750-21, *Logistic Support Modeling,* September 1973.
13. AMCR 750-28, *Depot Maintenance Program Scheduling, Workloading, and Reporting System,* August 1973.
14. AFM 25-5, *Management Engineering Policies and Procedures,* 8 August 1973.

GLOSSARY

Accessibility–The feature of design layout and installation which permits quick and easy admission (for performance of visual and manipulative maintenance) to the area in which a failure has been traced.

Achieved availability–The probability that materiel, when used under stated conditions in an ideal support environment (e.g., available tools, repair parts, and manpower), will operate satisfactorily at any given time. It excludes supply time and administrative downtime. Achieved availability is relatable directly to the early design process as a means of measuring equipment reliability and maintainability characteristics.

Active maintenance time–The time during which corrective or preventive maintenance is being performed on an item. Active maintenance time is comprised of the following task times: preparation time, fault location time, item obtainment time, fault correction time, adjustment and calibration time, and checkout time.

Adjustment and calibration time–The time for recalibration, retuning, etc., when adjustments are necessary, either to compensate for performance degradation or to compensate for differences between the operating characteristics of the replacement item and those of the original item.

Administrative and logistic time–The downtime due to nonavailability of repair parts, replacement parts, test equipment, or maintenance facilities, and the time due to nonavailability of maintenance technicians caused by administrative functions. Administrative and logistic downtime is not part of active repair time.

Allocated baseline–See: Baseline.

Assembly–A number of parts, or subassemblies, or any combination thereof joined together to perform a specific function and replaceable as a whole (e.g., hydraulic valve, amplifier).

Automatic Test Equipment (ATE)–Equipment that carries out a predetermined program of system testing for the detection, localization, and isolation of malfunctions to facilitate maintenance and the checkout of a system following maintenance.

Aviation intermediate support maintenance A level of Army aircraft maintenance that exists between the aviation unit and depot maintenance levels. It combines the previous functions of direct support and general support maintenance.

Aviation unit maintenance–Maintenance performed at the organizational level on Army aircraft. See also: Organizational maintenance.

Baseline–A configuration identification document or a set of such documents formally designated and fixed at a specific time during a configuration item life cycle. Baselines, plus approved changes from those baselines, constitute the current configuration identification. For configuration management there are three baselines:

Functional baseline–The initial approved functional configuration identification

Allocated baseline–The initial approved allocated configuration identification

Product baseline–The initial approved or conditionally approved product configuration identification.

Bug–To cause intentionally an actual or a simulated malfunction in materiel by adding or removing components, introducing adjustment errors, etc.

Calendar time–The total number of calendar days or hours in a designated period of observation.

Calibration–Those measurement services provided by designated depot and/or laboratory facility teams, who by the comparison of two instruments, one of which is a certified standard of known accuracy, detect and adjust any discrepancy in the accuracy of the instrument being compared with the certified standard.

Catastrophic **failure**–A sudden change in the operating characteristics of some part or parameter resulting in a complete failure of the item (e.g., circuit opens or shorts, structural failure).

Checkout–A madmachine task to determine that the equipment is operating satisfactorily and is ready for return to service.

Checkout time–The time required to check out the equipment after a maintenance action or otherwise to verify that a system or equipment is in satisfactory operating condition.

Cleanup time–The portion of total maintenance time following reassembly and checkout of an item in which tools, test equipment, and material not required for operation are removed from the equipment operating area.

Conceptual phase–The first phase in the materiel life cycle. The phase in which the technical, military, and economic basis for the program, and concept feasibility are established through pertinent studies and the development and evaluation of experimental hardware.

Confidence tests–Periodic test to verify that system performance is within specified limits and that the system is available for commitment to operational status if required. Confidence tests may be performed either as off-line tests (i.e., while the system is on standby) or as on-line measurement tests (during system operation) to assess performance quality.

Configuration control–The systematic evaluation, coordination, approval or disapproval, and implementation of all approved changes in the configuration of a configuration item after formal establishment of its configuration identification.

Configuration identification–The current approved or conditionally approved technical documentation for a configuration item as set forth in specifications, drawings and associated lists, and documents referenced therein.

Configuration item–An aggregation of hardware/software, or any of its discrete portions, which satisfies an end use function and is designated by the Government for configuration management. Configuration items may vary widely in complexity, size, and type, from an aircraft, an electronic or ship system to a test meter or round of ammunition. During development and initial production, configuration items are only those specification items that are referenced directly in a contract (or an equivalent in-house agreement). During the deployment phase, any repairable item designated for separate procurement is a configuration item.

Configuration management–**A** discipline applying technical and administrative direction and surveillance to (a) identify and document the functional and physical characteristics of a configuration item, (b) control changes to those characteristics, and (c) record and report change processing and implementation status.

Contract data requirements list (**CDRL**)–A listing (on DD Form **1423)** of all technical data and information required to be delivered to the Government by the contractor.

Contractor support–An arrangement during development or initial production of a system/equipment whereby the contractor is obligated to furnish to the Government items and services for the maintenance and support of the system/equipment.

Coordinated test program–A section of a materiel development plan that presents a coordinated plan for the accomplishment of all development and operational testing.

Corrective maintenance–That maintenance performed to restore an item to a satisfactory condition by providing correction of a malfunction that has caused degradation of the item below the specified performance.

Corrective maintenance action—Action required to repair a single failure; comprised of all those individual maintenance tasks involved in the maintenance procedure (e.g., fault localization, isolation, repair, and checkout).

Corrective maintenance time—The time that begins with the observance of a malfunction of an item and ends when the item is restored to a satisfactory operating condition. It may be subdivided into active maintenance time and nonactive maintenance time. It does not necessarily contribute to equipment or system downtime in cases of alternate modes of operation of redundancy.

Cost-effectiveness—A condition that exists when a function or mission is accomplished in a manner that satisfies operational or other applicable requirements at the lowest possible cost.

Debugging—A process of "shakedown operation" of a finished equipment to identify and correct workmanship errors, defective parts, etc., which may have escaped the quality control inspection procedures. Debugging usually is performed by the contractor prior to submission to Government acceptance test and normally is not part of the acceptance test. The debugging process also is useful in development for the detection and correction of inherent weaknesses in system design prior to submissison for maintainability demonstration and design approval.

Degradation failure—A failure that occurs as a result of a gradual or partial change in the characteristics of parts or materials (e.g., drift in electronic part characteristics, changes in lubricant with age, corrosion of metal).

Delay time—The component of downtime during which no maintenance is being accomplished on the item because of technician alert and response time, supply delay, or administrative reasons.

Deployment phase—The fifth phase in the materiel life cycle. During this phase, weapon systems/equipment become part of the operational inventory. Some documents combine this phase with the production phase into a single production and deployment phase.

Depot maintenance—Maintenance which is the responsibility of and performed by designated maintenance activities to augment stocks of serviceable materiel, and to support lower maintenance levels by the use of more extensive shop facilities and equipment and personnel of higher skills than are available at lower levels.

Design review—A multipurpose design verification procedure and project management tool used to evaluate the cumulative results of all the constituent design verification cycles at each of several designated major milestones in the acquisition program, to provide adequate engineering basis for timely iteration in the total system engineering cycle.

Developmental model—A model designed to meet performance requirements of the specification or to establish technical requirements for production equipment. This model need not have the required final form or necessarily contain parts of final design. It may be used to demonstrate the reproducibility of the equipment.

Development plan—The controlling document for a materiel development effort. Its preparation is initiated during the conceptual phase, and. the plan is refined and updated throughout the development process and subsequently when product improvement or changes to the materiel system occur.

Development Test I (DT 1)—A test conducted early in the development cycle, normally during the validation phase, to determine whether or not materiel is ready to enter full-scale production.

Development Test II (DT 11)—A test conducted to determine whether or not materiel is ready for production.

Development Test III (DT 111)—A test conducted on materiel from the initial production run to verify specification compliance.

Development testing—A series of materiel tests conducted by the Army developer, with or without contractor assistance, to assess program technical risks, demonstrate that engineering design is complete and acceptable, determine the extent of design risks, determine specification compliance, and assess production requirements.

Deviation—A specific written authorization, granted prior to the manufacture of an item, to depart from a particular performance or design requirement of a contract, specification, or referenced document, for a specific number of units and/or specific period of time. A deviation differs from an engineerng change in that an approved engineering change requires corresponding revision of the documentation defining the affected item, whereas a deviation does not contemplate revision of the applicable specification or drawing.

Direct maintenance resources—The time (in man-hours) and material (in dollars) expended directly on the item being maintained during the period of active maintenance.

Direct support maintenance—Maintenance normally authorized and performed by designated maintenance activities in direct support of using organizations.

Discard-at-failure maintenance—Maintenance accomplished by replacing and discarding a failed assembly, subassembly, module, or piece part. The term normally is associated with modules.

Disposal phase—The last phase of the system life cycle in which action is taken to provide for the systematic removal and disposal of materiel from the operational inventory.

Durability—A measure of the capability of materiel to meet or exceed its service life, or the time to a planned overhaul or rebuild.

Ease of maintenance—The degree of facility with which equipment can be retained in or restored to operation. It is a function of the rapidity with which maintenance operations can be performed to avert malfunctions or correct them if they occur. Ease of maintenance is enhanced by any consideration that will reduce the time and effort necessary to maintain equipment at peak operating efficiency.

End item—A combination of components, assemblies, and/or parts which is ready for its intended use. This will include complete systems as well as individual items; e.g., missile systems, aircraft with armament subsystems, a tank with radio set, an individual radio set, and generator.

Engineering change proposal (ECP)—A proposal to change the design or engineering features of materiel undergoing development or production.

Engineering release—The act of approval which establishes a document as the approved Government standard, specification, or drawing for identification, development, production, or acceptance of an item or system of equipment.

Equipment—One or more units and necessary assemblies, subassemblies, and parts, connected or associated together and including all necessary interconnecting cabling, hydraulic lines, accessories, etc., to perform an operational function (e.g., radio receiving set, missile, radar set). An equipment normally is not a replaceable item.

Equipment publications—Those publications dealing with the installation, operation, maintenance, and repair part support of Army materiel. Technical Manuals, Technical Bulletins, Lubrication Orders, and Modification Work Orders are the Department of the Army publication media used to provide these essential instructions for the major items of equipment.

Facility—A physical plant, such as real estate and improvements thereto, including buildings and equipment, which provides the means for assisting or making easier the performance of a function. Any part or adjunct of a physical plant or any item of equipment which is an operating entity and which contributes or can contribute to the execution of a function by providing some specific type of physical assistance.

Failure—Cessation of ability to perform a specified function within previously established or specified limits. A failure is a malfunction that cannot be adjusted by the operator by means of controls normally accessible to him during the routine operation of the device.

Failure analysis—The logical, systematic examination of an item to identify and diagnose the cause of observed failures.

Failure mechanism—A basic physical process or change which is responsible for the observed failure mode; the process of degradation or the chain of events which results in a particular failure mode.

Failure mode—A particular way in which failures occur, independent of the reason for failure; the condition or state which is the end result of a particular failure mechanism.

Failure mode and effects analysis (FMEA) The analysis of design to determine all possible ways in which failure can occur, to identify causes of failure, and to describe the consequences of failure on system performance.

Failure rate—The number of failures of an item per unit measure of life (cycles, time, miles, events, etc., as applicable).

Fault correction time—That element of active repair time required under a specified maintenance philosophy to correct the malfunction. It may consist of correcting the malfunction with the faulty item in place, removing and replacing the item with a like serviceable item, or removing the item for corrective maintenance and reinstalling the same item.

Fault detection time—Time between the occurrence of a failure and the point at which it is recognized that the system or equipment does not respond to operational demand during the mission sequence.

Fault isolation—See: Malfunction isolation.

Fault localization—See: Malfunction localization.

Fault location time—The portion of active repair time required to test and analyze and isolate an equipment malfunction.

Field maintenance—Maintenance authorized and performed by designated maintenance activities in direct support of using organizations.

Formal demonstration phase—A period of time during which maintainability demonstration tests are performed and data are acquired and analyzed, to determine conformance with specified requirements.

Full-scale development phase—The third phase in the materiel life cycle. During this phase, a system, including all items necessary for its support, is fully developed and engineered, fabricated, tested, and initially type-classified. Concurrently, nonmateriel aspects required to field an integrated system are refined and finalized.

Functional baseline—*See:* Baseline.

General-purpose test equipment—A category of test equipment, normally available in the supply system or from commercial stock, that can be used to test more than one system or equipment type.

General support maintenance– Maintenance authorized and performed by designated organizations in support of the Army supply system.

Hardware– See: Materiel.

Human engineering– The area of human factors which applies scientific knowledge to the design of items to achieve effective madmachine integration, operation, and maintenance.

Human factors– Human psychological characteristics relative to complex systems and the development and application of principles and procedures for accomplishing optimum madmachine integration and utilization. The term is used in a broad sense to cover all biomedical and psychosocial considerations pertaining to man in the system.

Indirect maintenance resources– That time in man-hours and material in dollars which, while not directly expended in active maintenance tasks, contributes to the overall maintenance mission, through the support of overhead operations, administration, accumulation of facility records and statistics, supervision, and facility upkeep.

Individual corrective maintenance **task time** M_{ct_i}–Time required to complete an individual maintenance task or an individual maintenance action.

Inherent availability– The probability that materiel, when used under stated conditions in an ideal support environment (e.g., available tools, repair parts, and manpower), will operate satisfactorily at any given time. It excludes preventive maintenance actions, supply time, and administrative downtime.

In-process review (**IPR**)– A review of a nonmajor program conducted at critical points in a materiel development cycle to evaluate military utility, accomplish effective coordination, and facilitate proper and timely decisions.

Interchangeability– A condition that exists when two or more items have such functional and physical characteristics as to be equivalent in performance and durability and capable of being exchanged one for the other without alteration to the items or the end item.

Integrated logistic support– A composite of all support considerations necessary to assure the effective and economical support of materiel for its life cycle. It is an integral part of all other aspects of materiel acquisition and operation. Integrated logistic support is characterized by harmony and coherence among materiel design and the planning and acquisition actions, as appropriate, associated with:

a. The maintenance plan
b. Support and test equipment
c. Supply support
d. Transportation and handling
e. Technical data
f. Facilities
g. Personnel and training
h. Logistic .support resource funds
2. Logistic support management information.

Intermediate maintenance– See: Field maintenance.

Isolation level– The functional level to which a failure can be isolated by the use of accessory test equipment at designated points.

Item obtainment time– The time required for the technician to obtain replacement parts, assemblies, or units, depending on the maintenance concept and the location and method of storing the supply items.

Life cycle– The life cycle embraces all phases through which materiel passes from the conceptual phase through the disposal phase.

Life cycle costs– The sum of the funds expended during the life cycle of materiel for development, test, procurement, operation, and support.

Life cycle maintenance (support) cost—The total cost of item maintenance during its useful life, including organizational, intermediate, depot, and contractor maintenance, repair part provisioning, test equipment, maintenance personnel salaries and subsistence, training, etc.

Logistic support analysis (LSA)—A process by which the logistic support necessary for a new system/equipment is identified. It includes the determination and establishment of logistic support design constraints, consideration of those constraints in the design of the "hardware" portion of the system, and analysis of the design to validate the logistic support feasibility of the design and to identify and document the logistic support resources which must be provided, as a part of the system/equipment, to the operating and support forces. Analytical techniques used to determine limited aspects of logistic support requirements are a part of the overall LSA process. Generally, logistic support analysis and maintenance engineering analysis functions are identical.

Logistic support analysis record (LSAR)—The final documentation of the logistic support analysis, recorded in deliverable form, that is the basic source of data related to the maintenance and logistic support for a specific item.

Logistic system, Army—A composite of the entire logistic activity of the Army at all levels.

Logistic time—The portion of downtime attributable to delay in the acquisition of replacement parts.

Logistics—Those aspects of military operations which deal with (a) design and development, acquisition, storage, movement, distribution, maintenance, evacuation, and disposal of materiel; (b) movement, evacuation, and hospitalization of personnel; *(c)* acquisition or construction, maintenance, operation, and disposition of facilities; and (d) acquisition or furnishing of services.

Maintainability—A measure of the ease and rapidity with which a system or equipment can be restored to operational status following a failure. It is a characteristic of equipment design and installation, personnel availability in the required skill levels, adequacy of maintenance procedures and test equipment, and the physical environment under which maintenance is performed. Maintainability is expressed as the probability that an item will be retained in or restored to a specified condition within a given period of time, when the maintenance is performed in accordance with prescribed procedures and resources.

Maintainability analysis—The formal procedure for evaluating system and equipment design, using prediction techniques, failure mode and effect analysis procedures, and design data, to evolve a comprehensive quantitative description of maintainability design status, problem areas, and corrective action requirements.

Maintainability data—Data (other than administrative data) resulting from the performance of maintainability tasks in direct support of an equipment or system acquisition program.

Maintainability demonstration tests—Government acceptance tests (performed by the contractor), usually at the equipment or subsystem level, for the major items which will comprise the integrated system to demonstrate conformance with specified quantitative maintainability requirements.

Maintainability engineering—The engineering discipline which formulates an acceptable combination of design features, repair policies, and maintenance resources, to achieve a specified level of maintainability, as an operational requirement at optimum life cycle costs.

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

Maintenance allocation chart (MAC)—A listing of maintenance operations applicable to an item of equipment with an indication of the lowest category of maintenance to which each operation is allocated. This chart will cover the major end item and accessories issued with the end item.

Maintenance analysis—The process of identifying required maintenance functions through analysis of a fixed or assumed design and determining the most effective means of accomplishing these functions.

Maintenance category—*See:* Maintenance level.

Maintenance concept—A description of the planned general scheme for maintenance and support of an item in the operational environment. The maintenance concept provides the practical basis for design, layout, and packaging of the system and its test equipment and establishes the scope of maintenance responsibility for each level of maintenance and the personnel resources (maintenance manning and skill levels) required to maintain the system.

Maintenance downtime rate $\overline{MDT}$—Equipment downtime per operating hour, comprised of downtime due to corrective maintenance and downtime required for preventive maintenance

Maintenance engineering—The application of techniques, engineering skills, and effort during the life cycle of materiel to insure the planning and implementation of an effective integrated logistic support program.

Maintenance engineering analysis—That part of the system engineering analysis process that is devoted to integrated logistic support. Maintenance engineering analysis is conducted throughout the life cycle of materiel and provides data required to:

a. Identify materiel design features that contribute to the ease and economy of logistic support

b. Establish cost-effective logistic support concepts and plans

c. Determine logistic support requirements

d. Identify, plan, and monitor the acquisition of resources that satisfy logistic support requirements.

Generally, maintenance engineering analysis and logistic support analysis functions are identical.

Maintenance environment—*See:* Operational environment.

Maintenance evaluation—A phase of maintenance support planning that begins in the conceptual phase and is completed prior to quantity production or procurement of the item for its initial entry into the Army inventory. It consists of maintenance engineering analysis, including teardown and test when necessary, of early production prototype and/or development models by maintenance engineers for the purpose of determining the most feasible method of supporting the equipment, determining the definitive requirements for support resources, completing maintainability analysis of selected equipments at the time of each in-process review, allocating maintenance operations to the appropriate maintenance levels, and detecting the maintenance parameters that have a favorable impact upon maintenance and, as a result, recommending design changes.

Maintenance factor—A factor used to indicate the number of expected failures of a repair part, expressed in the number of failures per 100 end items per year.

Maintenance float—End items or components of equipment authorized for stockage at installations or activities for replacement of unserviceable items of equipment when immediate repair of the unserviceable equipment cannot be accomplished by the support maintenance activity. Maintenance float includes both operational readiness float and repair cycle float:

Operational readiness float—End items or major components of mission essential, maintenance significant equipment authorized for stockage, normally by field maintenance units. or activities, to replace unserviceable equipment to meet operational commitments.

Repair cycle &at—An additional quantity of principal items of mission essential, maintenance significant equipment stocked at the depot level, to permit withdrawal of equipment from organizations for scheduled overhaul without detracting from the readiness of the unit. The float is used to cover equipments awaiting overhaul, in the overhaul process, and in transit to and from depot overhaul.

Maintenance **functions**—Actions that must be accomplished for a system or system element in order to return a failed system element to readiness (corrective maintenance functions) or to insure continuing normal system readiness (preventive maintenance functions).

Maintenance level—One of several organizational entities to which materiel maintenance functions may be assigned. The maintenance levels are organizational, direct support, general support, and depot. The direct and general support levels sometimes are combined into intermediate or field level.

Maintenance parameter—A design feature that impacts support resource requirements. These features may be related to reliability, maintainability, human factors, safety, and/or transportability.

Maintenance plan—A part of the plan for logistic support. The maintenance plan contains conditions of materiel utilization, reliability and maintainability requirements, the maintenance concept, a definition of the using and support organizations, maintenance test and physical teardown information, and a maintenance allocation chart.

Maintenance requirement card (**MRC**)—A card prepared to cover a specific planned maintenance action which contains the minimum required scheduling information and the step-by-step sequence for accomplishment.

Maintenance **resources**—*See:* Support subsystem.

Maintenance task—Any action or actions required to preclude the occurrence of a malfunction or to restore an equipment to satisfactory operating condition.

Major program—A designation assigned to a materiel acquisition program that requires it to be guided by decisions at the Secretary of Defense and/or Secretary of the Army/Chief of Staff level.

Malfunction—A general term that denotes the failure of a product to give satisfactory performance. It need not constitute a failure if readjustment of operator controls can restore an acceptable operating condition.

Malfunction isolation—An extension of malfunction localization wherein the exact cause of a malfunction is determined.

Malfunction localization—A madmachine task to determine which major unit of equipment is at fault.

Marginal testing—A procedure for system checking which indicates when some portion of the system has deteriorated to the point where there is a high probability of a system failure during the next operating period.

Material—Inventory goods on which manufacturing or processing must be done prior to sale or use.

Materiel—All tangible items (including ships, tanks, self-propelled weapons, aircraft, etc., and related repair parts and support equipment, but excluding real property, installations, and utilities) necessary to equip, operate, maintain, and support military activities without distinction as to application for administrative or combat purposes.

Maximum time to repair $M_{max_{ct}}$—The maximum time required to complete a specified percentage of all maintenance actions.

Mean—A quantity representing the average of two or more other quantities, arrived at by adding the quantities together and dividing by their number. Also called "arithmetic mean".

Mean corrective maintenance time $\overline{M}_{ct}$—The mean time required to complete a maintenance action (i.e., total maintenance downtime divided by total maintenance actions) over a given period of time. Mean time to repair (often denoted as *MTTR)* is the sum of all maintenance downtime during a given period divided by the number of maintenance actions during the same period of time.

Mean preventive maintenance time $\overline{M}_{pt}$—The mean (or average) equipment downtime required to perform scheduled preventive maintenance on the item, excluding any preventive maintenance time expended on the equipment during operation and excluding administrative and logistic downtime.

Mean time between failures (MTBF)—The total functioning life of a population of an item divided by the total number of failures within the population during the measurement interval. The definition holds for time, cycles, miles, events, or other measures of life units.

Mean time to repair—See: Mean corrective maintenance time.

Median corrective maintenance time $\widetilde{M}_{ct}$—The downtime within which 50 percent of all corrective maintenance actions can be completed under the specified maintenance conditions.

Median preventive maintenance time $\widetilde{M}_{pt}$—The equipment downtime required to perform 50 percent of ail scheduled preventive maintenance actions on the equipment under the specified conditions.

Mission essential materiel—That materiel assigned to strategic, tactical, general-purpose, or defense forces which is to be used by such forces to destroy the enemy or his capacity to continue war; to provide battlefield protection of personnel; to communicate under war conditions; to detect or locate the enemy; or to permit combat transportation and support of men and materiel.

Modification—A major or minor change in the design of an item of materiel, performed to correct a deficiency, to facilitate production, or to improve operational effectiveness.

Modification work order **(MWO)**—An official Department of the Army publication providing authentic and uniform instructions for the accomplishment of alteration and/or modification of materiel, and authority to perform the modification.

Module—A part, subassembly, assembly, or component designed to be handled as a single unit to facilitate supply and installation, operations, and/or maintenance. It either can be repairable or nonrepairable (discard-at-failure).

National Inventory Control Point (NICP)—An organizational segment, within the overall supply system of a commodity command, to which has been assigned responsibility for integrated materiel inventory management of a group of items.

National Maintenance Point (NMP)—The designated organizational element responsible for assigned maintenance functions of an Army agency charged with materiel development, production, maintenance engineering, and management of appropriate maintenance services for all applicable assigned commodity groups.

New-equipment training—All training for initial transfer of knowledge from the materiel developer to the user. This knowledge is needed to establish a training base or training capability for new or modified systems/equipment in major Army commands.

Nonactive maintenance time—The time during which no maintenance can be accomplished on the item because of administrative or logistic reasons.

Nonmajor program–A materiel acquisition program in which the Army Materiel Command normally has final decision-making authority. However, in some cases, this authority is retained by the Department of the Army Headquarters.

Operation profile–Various equipment status phases; i.e., calendar time, inactive time, demand usage time, operating time, and downtime.

Operational availability–The probability that materiel, when used under stated conditions in an actual operational environment, will operate satisfactorily when called upon.

Operational environment–A composite of all tangible and intangible factors that have an impact upon the operation and maintenance of materiel. It includes weather, terrain, hostile action, personnel fatigue, logistics, etc.

Operational factors–Various factors, generated by the operational concept, which enter into or affect the mission accomplishment. Among these factors are the number of vehicles, the in- and out-of-commision rates, availability requirements, combat readiness, and training requirements.

Operational parameter–Any operational requirement such as range, payload, availability, speed, and weight.

Operational readiness (OR)–The probability that, at any given time, a system or equipment is either operating satisfactorily or is ready to be placed in operation on demand when used under stated conditions, including stated allowable warning time. Thus, total calendar time is the basis for computation of operational readiness.

Operational test I (OT 1)–A test to assist in determining whether or not materiel should enter full-scale development.

Operational test II (OT 11)–A test accomplished prior to the production decision to assess materiel operational suitability and effectiveness.

Operational test III (OT 111)–A test accomplished with early production materiel to assess operational effectiveness, determine operational suitability, optimize organization, doctrine, and tactics, and validate training and logistic requirements.

Operational testing–A series of tests conducted by the designated user to determine operational effectiveness, suitability, and military desirability of materiel and the adequacy of the organization, doctrine, and tactics proposed for use.

Organizational maintenance – That maintenance which a using organization performs on its own equipment. This includes inspection, cleaning, servicing, preservation, lubrication, adjustment, minor repair not requiring detailed disassembly, and replacement not requiring high technical skill.

Packaging–A materiel design feature pertaining to the manner in which mechanical and electrical components are grouped into subassemblies, assemblies, modules, etc.; application or use of appropriate wrappings, cushioning, interior containers, and complete identification marking up to but not including the exterior shipping container.

Plan for logistic support–A major section of a materiel development plan that deals with all aspects of materiel support planning.

Predemonstration phase–A period of time immediately prior to commencement of formal maintainability demonstration during which the test team, facilities, and support materiel are assembled.

Preliminary maintenance allocation chart (PMAC)–A group of four charts prepared for materiel to indicate the authorized scope of repair parts and the degree of maintenance to be performed by each maintenance level.

Preparation time–The portion of active repair time required to obtain necessary test equipment and maintenance manuals, and set up the necessary equipment in preparation for fault location.

Preventive maintenance– The actions performed to retain an item at a specified level of performance by providing systematic inspection, detection, and prevention of impending failures.

Product baseline–See: Baseline.

Production model– A model in its final mechanical and electrical form of final production design made by production tools, jigs, fixtures, and methods.

Production phase– The fourth phase in the materiel life cycle. During this phase, all hardware, software, and trained personnel required to deploy an operational system are acquired. Some documents combine this phase with the deployment phase into a single production and deployment phase.

Project management– A concept for the technical, business, and administrative management of a specified project based on the use of a designated, centralized management authority who is responsible for planning, directing, and controlling all phases of research, development, and initial procurement, production, distribution, and logistic support for the purpose of providing a balanced program to accomplish the stated project objectives.

Project manager–**An** individual designated by the Secretary of the Army who is assigned the responsibility and delegated the full line authority for the centralized management of a specific project.

Prototype model– A model suitable for complete evaluation of mechanical and electrical form, design, and performance. It is in final mechanical and electrical form, uses approved parts, and is completely representative of final equipment.

Provisioning– The process of determining the range and quantity of items (i.e., repair parts, special tools, test equipment, and support equipment) required to support and maintain an end item of materiel for an initial period of service. It includes the identification of items of supply, the establishment of data for catalog, technical manual, and allowance list preparation, and the preparation of instructions to assure delivery of necessary support items with related end items.

Qualitative maintainability requirement– A maintainability requirement expressed in qualitative terms; e.g., minimize complexity, design for minimum number of tools and test equipment, design for optimum accessibility.

Quantitative maintainability requirement–A requirement expressed in quantitative terms; i.e., a figure of merit or in measurable units of time or resources required to accomplish a specific maintenance task or group of tasks in relation to the applicable performance requirements (reaction time, availabilities, downtime, repair time, turnaround time, etc.).

Random failure– A failure whose failure rate is constant and therefore follows the exponential density function and whose occurrence within any given interval of time therefore is unpredictable.

Reaction time– The time required to reach full operational capability from secure (equipment off) status following an alert command.

Ready time–The period of time during a mission when the item is available for operation but is not required.

Reassembly– A technician task for replacement of items removed to gain access to facilitate repair, and for closing the equipment for return to service.

Rebuild– To restore to a condition comparable to new by disassembling the item to determine the condition of each of its component parts, and reassembling it, using serviceable, rebuilt, or new assemblies, subassemblies, and parts.

Redundancy—The existence of more than one means for accomplishing a given task, when all means must fail before there is an overall failure of the system. Parallel redundancy applies to systems wherein both means are working at the same time to accomplish the task and either of the systems is capable of handling the job itself in case of failure of the other system. Standby redundancy applies to a system when there is an alternate means of accomplishing the task that is switched in by a malfunction-sensing device when the primary system fails.

Reliability—The probability that an item will perform its intended function for a specified interval under stated conditions.

Repair—The process of returning an item to a specified condition, including preparation, fault location, item procurement, fault correction, adjustment and calibration, and final test.

Replacement schedule—The specified periods when items of operating equipment are to be replaced. Replacement means removal of items aproaching the end of their maximum useful life, or the time interval specified for item overhaul or rework, and installation of a seviceable item in its place.

Request for proposal (RFP)—Documentation delivered by the Government to a contractor which describes a task to be accomplished, provides appropriate background information and constraints, and requests the contractor to submit a proposal to accomplish the task. The proposal is requested in a prescribed format that normally requires a contractor plan, costs, statement of capabilities, etc.

Retest phase—A period of time following a formal maintainability demonstration test for repeat tests in the event of a reject decision, or for the purpose of collecting data on untested maintenance actions.

Service life—The period of time during which an item can remain in the operational inventory under specified conditions of use and maintenance.

Serviceability—The design, configuration, and installation features that will minimize periodic or preventive maintenance requirements, including the use of special tools, support equipment, skills, and manpower, and enhance the ease of performance of such maintenance, including inspection and servicing.

Servicing—The performance of any act (other than preventive or corrective maintenance), such as lubrication, fueling, oiling, cleaning, etc., required to keep an item of equipment in operating condition. This does not include periodic replacement of parts or any corrective maintenance tasks.

Shelf life—The period of time during which an item can remain in storage without loss of performance capability or reliability.

Skill level—The classification system used to rate personnel as to their relative abilities to perform their assigned jobs.

Software—That portion of the support subsystem required in addition to personnel and hardware. Software includes technical data, computer programs and tapes, training documents, etc.

Standardization—The process of establishing, by common agreement, engineering criteria, terms, principles, practices, materials, items, processes, equipments, parts, subassemblies, and assemblies to achieve the greatest practicable uniformity of items of supply and engineering practices; to insure the minimum feasible variety of such items and practices; and to effect optimum interchangeability of equipment parts and components.

Supply delay time—The portion of delay time during which a needed item is being obtained from other than the designated organizational stockroom.

Support cost—The total cost of ownership, excluding operating crews and using personnel, of an item during its operational life, including the total impact of requirements for skill levels, technical data, test equipment, repair parts, special tools, operational and maintenance equipment, facilities, levels and location of maintenance facilities, manpower, training, and training equipment.

Support **equipment**—Items necessary for the maintenance or operation of the system which are not physically part of the system.

Support parameter—Any of the several categories of support resources, such as personnel, repair parts, and facilities, required to support materiel.

Support profile—A composite summary of all data and information on support concepts and characteristics, including logistic burden, task and skill requirements, and other factors that will indicate the total impact of support parameters applicable to specific conceptual or technological approaches or system and equipment configuration.

Support **resources** —See: Support subsystem.

Support subsystem—That portion of a weapon system which consists of tools, test equipment, repair parts, trained personnel, technical documentation, facilities, etc., and similar indirect support resources.

Support synthesis—The assembly of support activities, which are feasible at various maintenance levels, into complete support concepts.

Supportability—A measure of the capability of materiel to be supported easily and economically.

System—See: Weapon system.

System effectiveness **(SE)**—The probability that a system successfully can meet an operational demand within a given time when operated under specified conditions.

System engineering—The application of scientific and engineering knowledge to the planning, design, construction, and evaluation of madmachine systems and components. It includes the overall consideration of possible methods for accomplishing a desired result, determination of technical specification, identification and solution of interfaces among parts of the system, development of coordinated test programs, assessment of data, integrated logistic support planning, and supervision of design work.

Task and skill analyses—The process of analyzing materiel, hardware, items, or systems to identify all tasks necessary for proper operation, maintenance, and repair of materiel in accordance with the mission, employment doctrine, and support concept. The process includes an analysis of tasks to provide specified data, such as skill demand, frequency, date by which personnel will be required, location, etc., and a description of the task steps required to complete the performance of the task.

Task data—The data which describe a task and the data, obtained through task analysis, which modify or qualify the task. Task data may be needed for achieving all the human factor objectives. Task data are useful for human factors engineering, training, design or training devices, analysis of organization of personnel requirements (including qualitative and quantitative personnel requirement information), technical manuals, and human factor test and evaluation.

Technician delay time—The delay time incurred during a maintenance task because of supply or administrative reasons.

Test—A process by which data are accumulated to serve as a basis for assessing the degree that an item or system meets, exceeds, or fails to meet the technical or operational properties required of the system.

Test and checkout level—The functional level at which restoration to normal services is to be verified by the use of self-test or other testing facilities.

Test, **Measurement,** and Diagnostic Equipment **(TMDE)**—Any system or device used to evaluate the operational condition of materiel to identify and/or isolate any actual or potential malfunction.

Test point—A convenient and safe access to functional portions of materiel which is to be used so that a significant quantity can be measured or introduced to facilitate maintenance, repair, calibration, alignment, or monitoring.

Tolerance failure—A system or equipment failure resulting from multiple drift and instability problems, even though part failures may not have occurred. Tolerance failure rate increases as a function of system complexity.

Total **downtime**—The portion of calendar time during which a system is not in condition to perform its intended function; includes active maintenance (preventive and corrective), supply downtime due to unavailability of needed items, and waiting and administrative time.

Trade-off—A comparison of two or more ways of doing something in order to make a decision. Decision criteria normally are quantitative.

Transportability—The inherent capability of materiel to be moved by towing, self-propulsion, or by carrier via railways, highways, waterways, ocean, and airways.

Troubleshooting—Identifying materiel malfunction symptoms and localizing and isolating the cause of the malfunction.

Turnaround time—The portion of maintenance time needed to service or check out-an item prior to recommitment.

Type classification—Action required for the purpose of providing a basis upon which to judge the current qualitative adequacy of Army materiel; to record the status of an item in relation to its overall life history; and to plan and carry out its procurement, issue, maintenance, and disposal.

Useful **life**—The total operating time in which an item remains operationally effective and economically useful before wearout.

Validation phase—The second phase in the materiel life cycle. This phase consists of those steps necessary to resolve or minimize special logistic problems identified during the conceptual phase, verify preliminary design and engineering, accomplish necessary planning, fully analyze trade-off proposals, and prepare contracts as required for full-scale development.

Weapon system—A weapon and those components required for its direct operation and maintenance. The complete weapon system includes the related facilities, materiel, services, and personnel required to make it self-sufficient in its operational environment.

Wearout **failure**—A failure that occurs as a result of deterioration or mechanical wear and whose probability of occurrence increases with time. Wearout failures occur generally near the end of the life of an item and usually are characterized by chemical or mechanical changes. These failures frequently can be prevented by adopting an appropriate replacement policy based on the known wearout characteristics of the item.

Work breakdown structure—A product-oriented family tree, composed of hardware, software, and services and other work tasks, which results from project engineering effort during the development and follow on production of a defense materiel item, and which completely defines the project/program.

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