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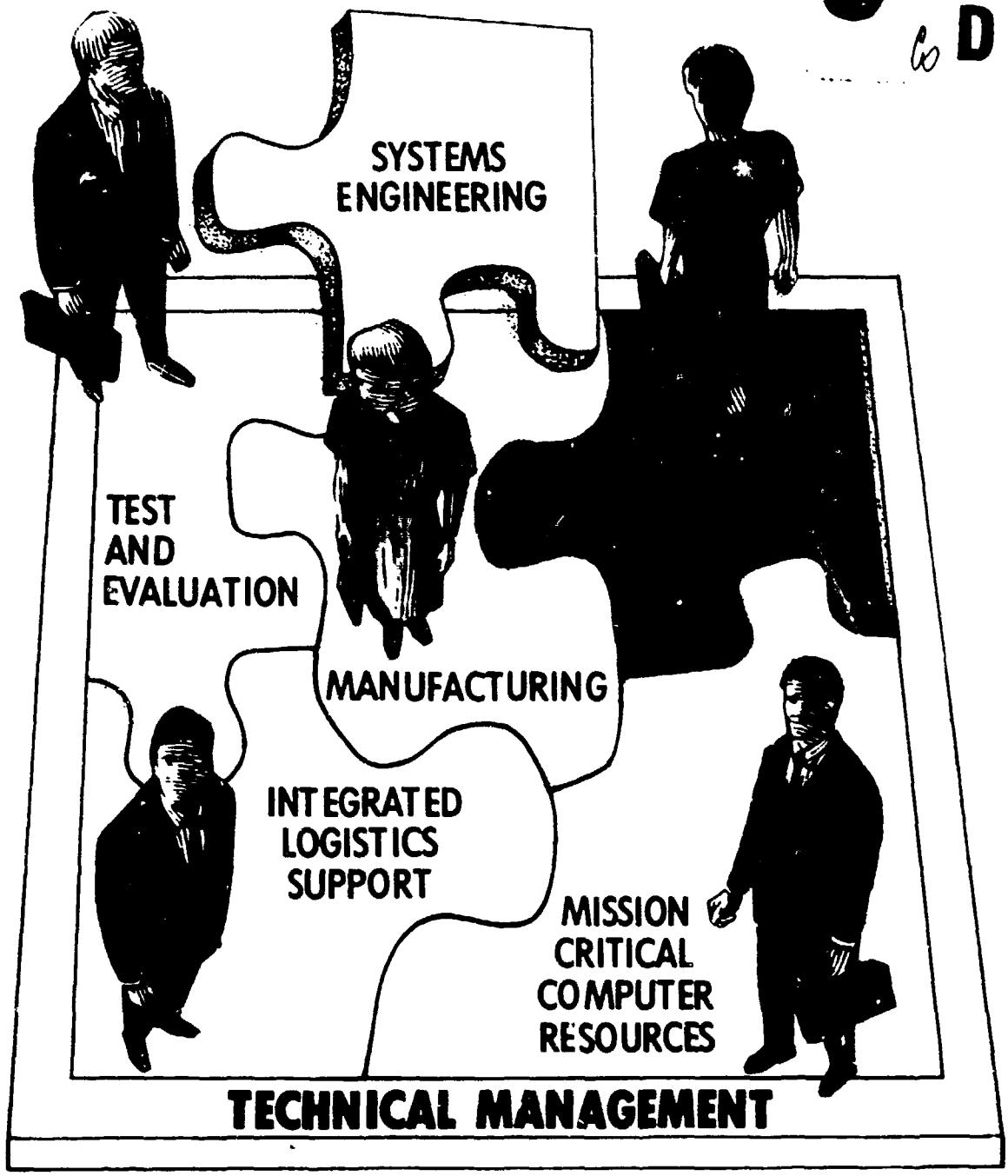
SYSTEMS ENGINEERING MANAGEMENT GUIDE

JANUARY 1990



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This document is one of a family of educational acquisition management guides written from a Department of Defense (DOD) perspective; e.g., non-service peculiar. They are intended primarily for use in the courses offered by the Defense Systems Management College (DSMC) and secondarily as desk references for DOD Acquisition Managers. This family of guides consists of: 1) Integrated Logistics Support Guide, 2) Mission Critical Computer Resources Management Guide, 3) Test and Evaluation Management Guide, 4) Risk Management Concepts and Guidance, 5) DOD Manufacturing Management Handbook, and 6) Subcontracting Management Handbook.

This Systems Engineering Management Guide (SEMG) is designed to 1) acquaint the newcomer with systems engineering concepts and techniques and 2) identify relevant directives and references. These concepts, when combined with common sense and technical expertise, constitute the basis of a sound systems engineering program. The SEMG highlights the technical management activities over the system's life cycle from program (cont'd on reverse)

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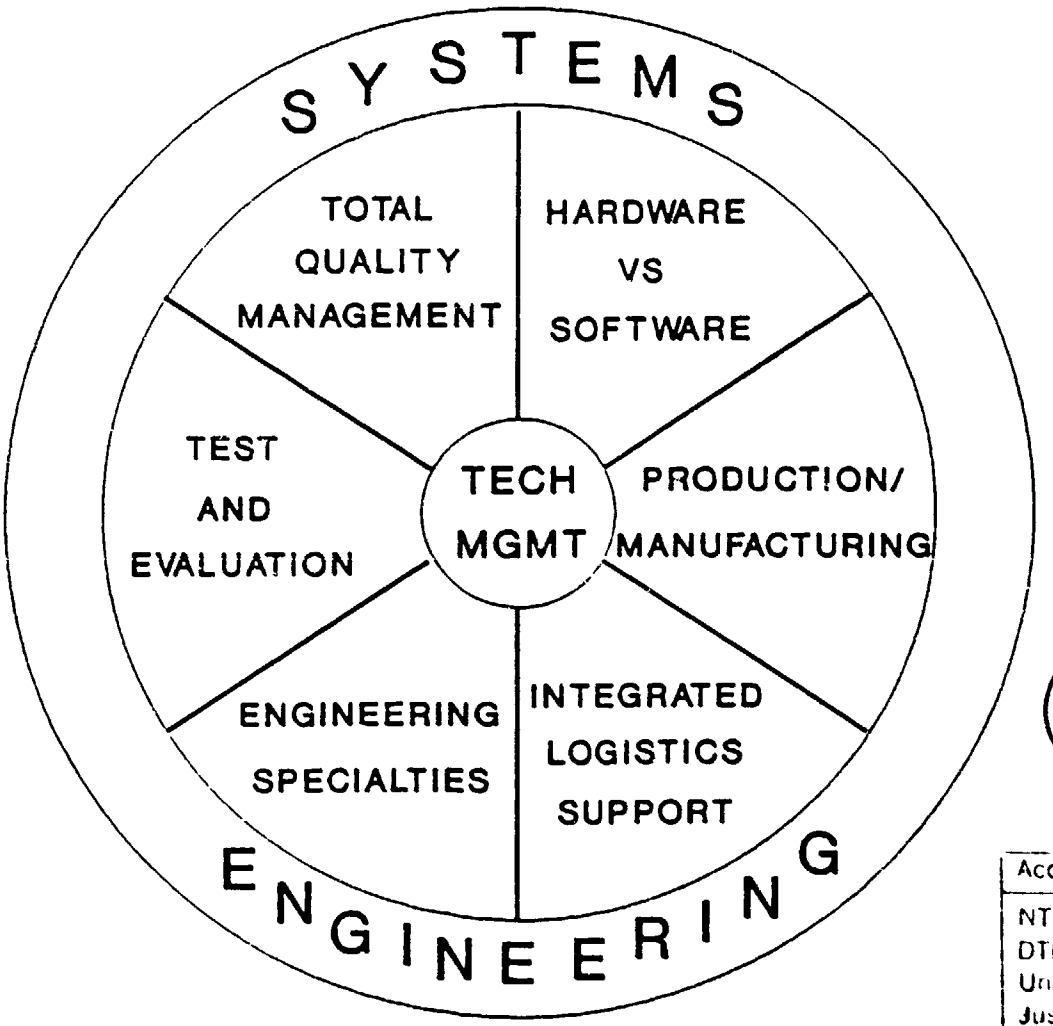

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FOREWORD

This document is one of a family of educational acquisition management guides written from a Department of Defense (DoD) perspective; e. g., non-service peculiar. They are intended primarily for use in the courses offered by the Defense Systems Management College (DSMC) and secondarily as desk references for DoD Acquisition Managers. This family of guides consists of: 1) Integrated Logistics Support Guide, 2) Mission Critical Computer Resources Management Guide, 3) Test and Evaluation Management Guide, 4) Risk Management Concepts and Guidance, 5) DoD Manufacturing Management Handbook, and 6) Subcontracting Management Handbook.

This Systems Engineering Management Guide (SEMG) is designed to 1) acquaint the newcomer with systems engineering concepts and techniques and 2) identify relevant directives and references. These concepts, when combined with common sense and technical expertise, constitute the basis of a sound systems engineering program. The SEMG highlights the technical management activities over the system's life cycle from program initiation to system disposal. All activity centers around the system itself; thus, the system configuration at any time is of common interest to all engineering disciplines. These activities are normally divided into functional areas of design, test, manufacturing, and logistics support. Each of these functional areas is active throughout the system's life cycle.

The effort involved in the acquisition process can be modeled as an input, process, and output. The input is the need and constraints provided by the user. The process consists of managing the technical activities by establishing and maintaining a balance among system effectiveness, schedule, and cost. This is accomplished through systems engineering. The output is the system itself. The goal of the acquisition process, therefore, is to deploy, in a timely manner, and sustain an effective system that satisfies a specific user's need at an affordable cost.

To summarize, management of the acquisition process can be defined as the logical and systematic effort required to transform a military need into an operational system which requires a cooperative effort on the part of government and industry. The capability of the industrial base to economically produce Defense systems, on a timely basis, is a key element of the acquisition process.

This guide book was developed primarily by the following members of the DSMC Technical Management Department Systems Engineering staff:

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CHAPTER 1

SYSTEMS ENGINEERING OVERVIEW

1.1 INTRODUCTION

The objective of this guide is to familiarize you with the role that systems engineering plays in the development of a weapon system. It will focus primarily on the relationship between the technical management process and the systems engineering process. The guide is based on the tasks defined in MIL-STD-499A [1], and the concepts and processes defined in "Systems Engineering and Analysis", by Benjamin S. Blanchard [2]. The guide is intended to provide the perspective and background data in systems engineering necessary for effective overall program management. It relates the diverse elements of systems engineering not only to each other, but to overall system effectiveness in satisfying a defined user need at an affordable cost.

1.2 EVOLUTION OF SYSTEMS ENGINEERING

The past several decades have seen the rise of large, highly interactive systems that are on the forward edge of technology. As a result of this growth and the increased usage of digital systems (computers and software), the concept of systems engineering has gained increasing attention. Some of this attention is no doubt due to large program failures which possibly could have been avoided, or at least mitigated, through the use of systems engineering principles. The complexity of modern day weapon systems requires conscious application of systems engineering concepts to ensure producible, operable, and supportable systems that satisfy mission requirements.

Although many authors have traced the roots of systems engineering to earlier dates, the initial formalization of the systems engineering process for military development began to surface in the mid-1950s on the ballistic missile programs. These early ballistic missile development programs marked the emergence of engineering discipline "specialists" which has since continued to grow. Each of these specialties not only has a need to take data from the overall development process, but also to supply data, in the form of requirements and analysis results, to the process.

A number of technical instructions, military standards and specifications, and manuals were developed as a result of these development programs. In particular, MIL-STD-499 was issued in 1969 to assist both government and contractor personnel in defining the systems engineering effort in support of defense acquisition programs. This standard was updated to MIL-STD-499A [1] in 1974, and formed the foundation for current application of systems engineering

principles to military development programs.

1.3 DEFINITIONS OF SYSTEMS ENGINEERING

MIL-STD-499A [1] defines systems engineering as:

" ***the application of scientific and engineering efforts to (a) transform an operational need into a description of system performance parameters and a system configuration through the use of an iterative process of definition, synthesis, analysis, design, test, and evaluation; (b) integrate related technical parameters and ensure compatibility of all physical, functional, and program interfaces in a manner that optimizes the total system definition and design; (c) integrate reliability, maintainability, safety, survivability, human engineering, and other such factors into the total engineering effort to meet cost, schedule, supportability, and technical performance objectives*** ".

In its simplest terms, systems engineering is both a technical process and a management process. The above definition focuses in on the technical aspects. To successfully complete the development of a system, both aspects must be applied throughout the system life cycle. From a government's program management point of view, DSMC favors the management approach and defines systems engineering as follows:

"***Systems engineering is the management function which controls the total system development effort for the purpose of achieving an optimum balance of all system elements. It is a process which transforms an operational need into a description of system parameters and integrates those parameters to optimize the overall system effectiveness***".

A system life cycle begins with the user's needs, expressed as constraints, and the capability requirements needed to satisfy mission objectives. Systems engineering is essential in the earliest planning period, in conceiving the system concept and defining system requirements. As the detailed design is being done, systems engineers assure: 1) balanced influence of all required design specialties, 2) resolve interface problems, 3) conduct design reviews, 4) perform trade-off analyses, and 5) assist in verifying system performance. During the Production phase, systems engineering is concerned with: 1) verifying system capability, 2) maintaining the system baseline, and 3) forming an analytical framework for producibility analysis. During the Operation and Support (O/S) phase, systems engineering: 1) evaluates proposed changes to the systems, 2) establishes their effectiveness, and 3) facilitates the effective incorporation of changes, modifications, and updates.

1.4 THE SYSTEMS ENGINEERING PROCESS

Although programs differ in underlying requirements, there is a consistent, logical process for best accomplishing system design tasks. Figure 1-1 illustrates the activities of the basic systems engineering process. This process is described in detail in Chapters 5 through 8 of this guide.

The systems engineering process is iteratively applied. It consists primarily of

four activities: 1) functional analysis, 2) synthesis, 3) evaluation and decision, and 4) a description of systems elements. The product element descriptions become more detailed with each application and support the subsequent systems engineering design cycle. The final product is production-ready documentation of all system elements.

1.5 SYSTEMS ENGINEERING OBJECTIVES

Since the requirement to implement a systems engineering process may cause major budgetary commitments and impact upfront development schedules, it is important to understand the inherent objectives:

a. Ensure that system definition and design reflects requirements for all system elements: equipment, software, personnel, facilities, and data.

b. Integrate technical efforts of the design team specialists to produce an optimally balanced design.

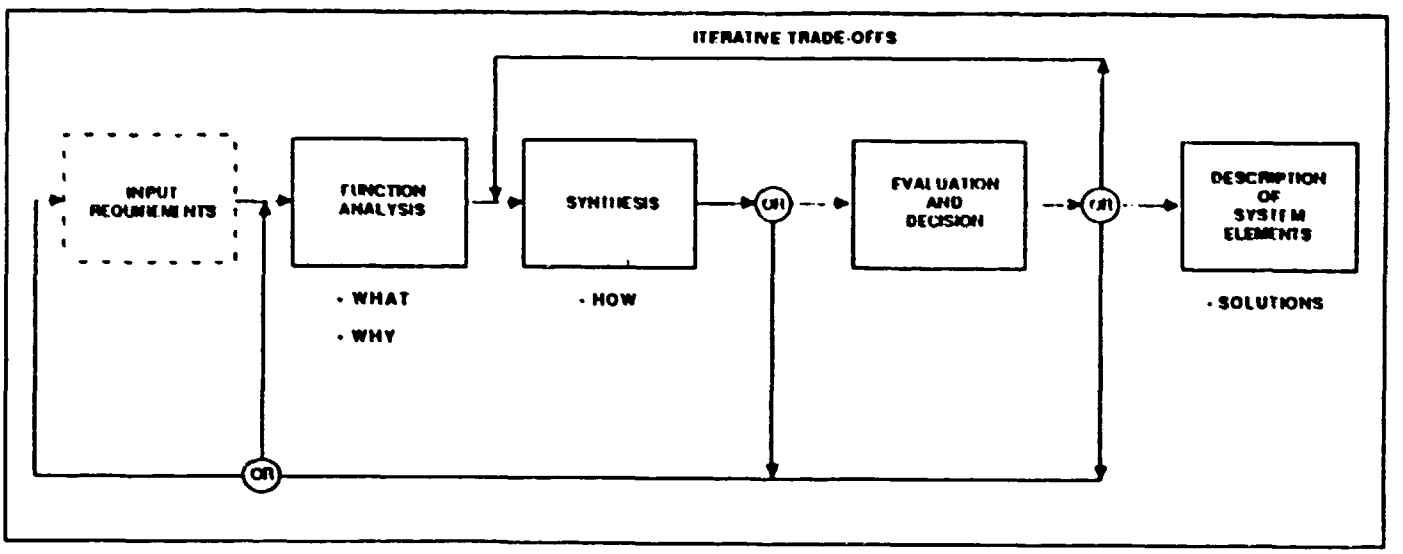
c. Provide a comprehensive indentured framework of system requirements for use as performance, design, interface, support, production, and test criteria.

d. Provide source data for development of technical plans and contract work statements.

e. Provide a systems framework for logistic analysis, integrated logistic support (ILS) trade studies, and logistic documentation.

f. Provide a systems framework for production engineering analysis, producibility trade studies, and production/manufacturing documentation.

Figure 1-1
The Systems Engineering Process



g. Ensure that life cycle cost considerations and requirements are fully considered in all phases of the design process.

1.6 SYSTEMS ENGINEERING IMPLEMENTATION

Successful application of systems engineering requires:

a. Mutual understanding and support between the military and contractor Program Managers. They must be willing to make the systems engineering process the backbone of the overall development program.

b. Understanding the need to define and communicate among the engineering specialty programs.

c. Recognition of the role of formal technical reviews and audits, as described in MIL-STD-1521B [3], including the value, objectives, and uniqueness of each formal review and audit.

d. Knowledge of the objectives of the program.

e. A thorough interpretation of the user's requirements.

1.7 SYSTEMS ENGINEERING OUTPUTS

The output of the systems engineering process is documentation. This is the means by which it controls the evolutionary development of the system. Systems engineering prepares a number of technical management and engineering specialty plans which define how each phase of the acquisition cycle will be conducted. Draft plans are usually submitted with the proposal and final plans are delivered in accordance with the Contract Data Requirements List (CDRL). These plans are used by the government to ensure compliance with the contract and used by the contractor to develop detailed schedules and allocation of resources. Specifications are submitted which form the basis for the design and development effort. Top level specifications are incorporated into the statement of work (SOW) and provided to the developer. The developer will allocate these top level requirements to lower level system components (hardware and software) and submit the associated specifications and design documents to the government for approval. The status of system development progress is tracked and documented in the form of technical review data packages, technical performance measurement (TPM) reports, analysis and simulation reports, and other technical documentation pertinent to the program. In summary, this documentation may include:

a. Systems Engineering Management Plan (SEMP)

b. Specifications (system, segment, development, product, process, material,)

c. Design Documentation

d. Interface Control Documents (ICDs)

e. Risk Analysis Management Plan

f. Survivability/ Vulnerability (S/V) Hardness Plan

g. Mission Analysis Report

h. Reliability Plan

i. Maintainability Plan

j. Integrated Logistics Support Plan (ILSP)

k. Software Development Plan (SDP)

l. Test and Evaluation Master Plan (TEMP)

m. Producibility Plan

n. Functional Flow Block Diagrams (FFBD)

o. Requirements Allocation Sheets (RAS)

p. Audit Reports

q. EMI/EMC Control Plan

r. Human Engineering Plan

s. Trade Study Reports

1.8 REFERENCES

1. MIL-STD-499A, "Engineering Management", 1 May 1974.

2. Blanchard, Benjamin S. and Fabrycky, Wolter J., "Systems Engineering and Analysis", Englewood Cliffs, New Jersey; Prentice-Hall Inc., 1981.

3. MIL-STD-1521B, "Technical Reviews and Audits for Systems, Equipments, and Computer Software", 4 June 1985

CHAPTER 2

SYSTEMS ENGINEERING IN THE ACQUISITION PROCESS

2.1 INTRODUCTION

Throughout any design process, systems engineering is used to identify and define the functional characteristics of system hardware, software, facilities, data, and personnel. It is an interactive process of analysis and design, with the objective of satisfying an operational mission need in the most cost-effective manner. The systems engineering process is used to analyze mission requirements and translate them into design requirements at successively lower levels.

This chapter discusses systems engineering in the context of the Department of Defense (DoD) acquisition process. A description of government acquisition policies and the relationship of the systems engineering process with the life cycle of a typical system are included.

2.2 GOVERNMENT ACQUISITION POLICIES

The Department of Defense uses a systematic technical management process to control acquisition programs, as illustrated in Figure 2-1. The DoD acquisition process for major systems has its foundation in federal policy.

In the early 1970s, the Office of Federal Procurement Policy (OFPP) was established to provide policies, methods, and criteria for the acquisition of property and services for all executive agencies. In 1976, the Office of Management and Budget (OMB) Circular A-109 was published with the goal of increasing management effectiveness on major system acquisitions. The circular laid the foundation for standardizing the government acquisition process and promoting unbiased concept definition. OMB Circular A-109 requires the government operating agency to establish and justify a valid requirement for a capability, which must be approved by the executive agency head (e.g.; Secretary of Defense (SECDEF), NASA Administrator) before involving industry in the system acquisition process.

The principal guidance for defense system acquisitions is DoDD 5000.1, "Major and Non-Major Defense Acquisition Programs" [1] and DoDI 5000.2, "Defense Acquisition Program Procedures" [2]. These documents reflects certain acquisition management principles and objectives:

a. Ensure effective design and price competition

b. Improve system readiness and sustainability

c. Increase program stability through

effective long-range planning, use of evolutionary alternatives, realistic budgeting and funding of programs for the total life cycle, and planning to achieve economical production rates

d. Delegate authority to the lowest levels of the service that can provide a comprehensive review of the program

e. Achieve a cost-effective balance between acquisition costs, ownership costs, and system effectiveness in terms of the missions to be performed.

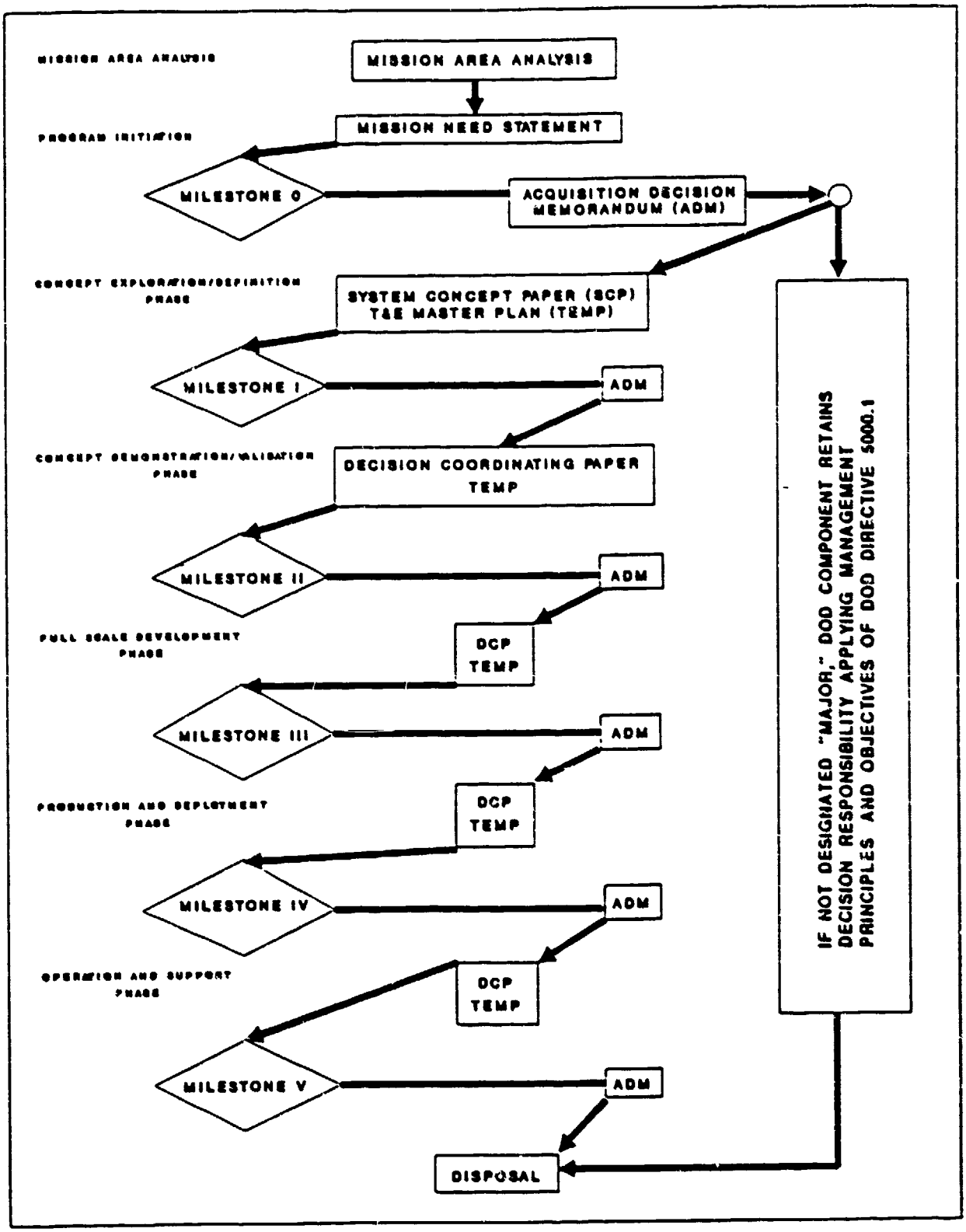
2.3 SYSTEM LIFE CYCLE

The acquisition process for major defense systems, defined in DoDD 5000.1 and DoDI 5000.2, is depicted in Figure 2-1 and consists of five primary phases: Concept Exploration/ Definition (C/E), Concept Demonstration/ Validation (D/V), Full Scale Development (FSD), Production and Deployment (P/D), and Operation and Support (O/S). Within DoD, major systems are defined as systems anticipating funding levels of more than $200 million in research, development, test, and evaluation or $1 billion in procurement in constant FY-80 (fiscal year 1980) dollars. The process begins by conducting mission area analysis efforts in determining the user's mission need, followed by an approval for program initiation and authority to budget for a new program (Milestone 0 decision). Next, the program normally enters the C/E phase during which all reasonable system alternatives are explored. The program then enters the D/V phase (Milestone I decision) during which the preferred system concepts are selected and tested to identify risk areas and to demonstrate that all experimental efforts have been completed. The results of these efforts are reviewed and the program is allowed to enter into the FSD phase (Milestone II decision) where system detailed design and test are performed. Once completed, the system is approved to proceed with full-rate production and initial deployment in the P/D phase (Milestone III decision) during which the actual production or construction takes place. The initial deployment also marks the beginning of the O/S phase. A review will be conducted one to two years after initial deployment to assure that the operational readiness and support objectives are being achieved (Milestone IV decision). Later, during the O/S phase, modifications and product improvements are usually implemented. Another review will be conducted somewhere between five to ten years after initial deployment (Milestone V decision) to determine if major upgrades are needed.

At the end of each phase, as noted above, the need for the program is re-certified, using milestone decision reviews, by the Secretary of Defense (SECDEF) or the Service Secretary, as required, before additional resources are authorized. At each review, the decision authority can choose to continue the present phase, proceed to the next phase, or cancel the program. The SECDEF can also direct a DoD program to omit C/E and/or D/V and proceed directly into FSD as special circumstances prevail.

The SECDEF is assisted in this decision-making role by the Defense Acquisition Board (DAB), chaired by the Under Secretary of Defense for Acquisition (USD(A)). The DAB has broad review responsibility for Milestones I through V;

Figure 2-1
Acquisition Process for Major Defense Systems



aids SECDEF in defining and validating new system requirements; examines trade-offs between cost and performance; explores alternatives to new research and development starts; and recommends full scale development and full rate production.

The following discussion focuses on the acquisition process for major defense systems. A modified approach, unique to each service, is employed for non-major or non-developmental systems. Although the approval authority level for the non-major systems is not as high as the USD(A), the aspects of the program that must be demonstrated are identical. Non-major systems may not follow all of the acquisition phases that major systems do. They will, however, have a development and review cycle appropriate to the nature and scope of the program in accordance with the streamlining process outlined in Chapter 10 of this guide. Acquisition of non-major systems is directed by the service or major command, as appropriate. Each service has its own system of reviews and approvals that achieves objectives similar to the DoD cycle.

2.3.1 Program Initiation\ Mission Need Decision

Mission area analysis (MAA) is an ongoing activity for identifying deficiencies in existing defense capabilities or determining more effective means of performing assigned tasks within assigned mission areas. When deficiencies or opportunities may be identified, system performance requirements are established. MAA takes cognizance of changes in national defense policy, external threats, and technological capabilities. The analysis considers alternatives to new development such as redeployment of existing military resources, use of commercial systems, or tactics changes. When no other alternative is available, the product of this activity is development of the Mission Need Statement (MNS). The MNS defines the mission need, identifies constraints, and outlines the initial acquisition strategy.

2.3.2 Concept Exploration/ Definition Phase

C/E is initiated following the DAB approval of the MNS and the issuance of the Acquisition Decision Memorandum (ADM). The USD(A) forwards the ADM to the SECDEF for his endorsement of this proposed new start and designation as a major system. The MNS is normally included in the service Program Objectives Memorandum (POM).

During C/E, system concepts are defined and selected for further development. The systems engineer, working through private industry and DoD research and development (R&D) agencies, identifies all reasonable system alternatives that may satisfy the mission need and makes recommendations to the program office. The Program Manager then selects those alternatives or concepts which meet cost, risk, schedule, and readiness objectives.

Alternative system design concepts are explored through competitive, parallel, short-term contracts; alternative methods of logistic support are examined through logistic support analysis; and producibility is analyzed through producibility engineering and planning. Contractors are provided with operational employment intentions, mission performance criteria, and life cycle cost

(LCC) estimating factors. Affordability is assessed and early gross LCC estimates of the competing alternatives are made. Design to cost (DTC) constraints are used to indictate which producibility and production efficiencies are required.

The industry's systems engineering activity during this period is based on system requirements provided with the statement of work (SOW). These requirements are translated into alternative design concepts, through functional analysis, synthesis, and trade-off analysis. For each segment of the design concept, allocated requirements, interface identifications, and technical budgets are produced as systems engineering products. The industry output is reviewed by the government for:

a. Capability of the proposed system to meet the mission need and program objectives, including resources required and associated risk levels

b. Benefits to be derived by trade-offs among technical performance, operational effectiveness and suitability (system effectiveness), LCC (including age and operation), and schedule (time to develop, manufacture, and field)

c. Relevant development experience and performance record of each competitor and the competence of competitors' key systems engineering and design personnel.

System descriptions, and associated risk, cost, and development time estimates are used by the government to establish a system functional baseline, usually in the form of a Type A system specification (refer to MIL-STD-490A [3]). This baseline should not constitute selection of a specific design concept, but rather identification of feasible, affordable ranges of cost and system effectiveness. Proper identification is essential to an effective acquisition strategy since real competition requires a system level specification which can be met by more than one design concept.

Systems Engineering Management Plans (SEMPs), Integrated Logistic Support Plans (ILSPs), Computer Resources Life Cycle Management Plans (CRLCMPs), Test and Evaluation Master Plans (TEMPs), and other functional plans are normally initiated during this phase. A System Requirements Review (SRR) is accomplished to determine the extent to which selected contractor design concepts satisfy the stated mission need.

In order to support the Milestone I decision, a System Concept Paper (SCP) is prepared to summarize the results of the C/E phase; an initial Test and Evaluation Master Plan (TEMP) is developed to address program test requirements; and other documentation is prepared to establish the program charter and to refine the program acquisition strategy as necessary.

The SCP for a major system is reviewed first by the service component's System Acquisition Review Council (SSARC), and if approved, by the DAB. The DAB review at Milestone I reconfirms the program need, determines that program risks were adequately considered, and ensures that adequate planning for technical performance, supportability, test and evaluation, producibility, and life cycle costing was established. When the SCP meets all of

these objectives, it is forwarded to the SECDEF with recommendations to proceed to D/V or FSD. Approval by the SECDEF is documented in the ADM and authorizes the service to prepare and release a request for proposal (RFP) for the approved phase.

2.3.3 Concept Demonstration/Validation Phase

The D/V phase is normally initiated by the release of the ADM. The D/V phase RFP may be released prior to the ADM; however, contract award must follow the ADM. The D/V phase RFP contains a system level specification, the program management approach, and the SOW describing the scope of the contractor effort. After proposal evaluation and contract award, systems engineering becomes a contractor effort, often by two or more contractors. The government usually assumes a systems engineering management role.

The objective in the D/V phase is to identify and analyze major system alternatives, to examine risky subsystems, and to determine whether or not to proceed into FSD. The main products of this phase are normally a validated system specification (Type A) which determines the system functional baseline and an initial set of subsystem performance development specifications. When validated, these development specifications (Type B) will determine the allocated baseline for the system. The allocated baseline is also referred to as the "design requirements" or the "design to" baseline. It incorporates technological approaches developed to satisfy requirements established at the system level by the functional baseline.

Another major product of the D/V phase is the Systems Engineering Management Plan (SEMP), which includes plans for risk alleviation and identifies the schedule for producing all required plans for the supporting engineering specialties, such as electromagnetic compatibility/ electromagnetic interference (EMC/ EMI), safety, reliability, maintainability, integrated logistic support, and human engineering. MIL-STD-499A [4] details the information to be included in the SEMP and suggests that it be tailored to suit contractor requirements. Chapter 3 of this guide addresses the considerations of SEMP development, timing, and format. Other products include updated ILSPs, CRLCMPs, and TEMPs.

As the systems engineering process progresses from the functional to the allocated baselines, required configuration items (CIs) are identified. The process includes trade-off analyses to ensure that the system will satisfy the functional baseline with the optimal balance of LCC, schedule, and system effectiveness. Logistic support analyses are conducted to identify and analyze logistic support alternatives for the system. The selected support alternative is documented in the ILSP.

Elements of the proposed system are continually assessed to identify areas of technical uncertainty that must be resolved in later program phases (risk assessment). Critical components may be prototyped to reduce risk. A System Design Review (SDR) is held at the end of the D/V phase (or early in the FSD phase) to review the preliminary allocation of requirements to hardware CIs (HWCI), computer software CIs (CSCI), personnel, facilities, and data.

A Decision Coordinating Paper (DCP) is prepared by the SSARC(s) for review by the DAB. If all requirements are satisfied, a ratified ADM recommending FSD approval is forwarded to the SECDEF. Once approved, the ADM authorizes the service to prepare and release an RFP for FSD activities.

2.3.4 Full Scale Development Phase

To initiate the FSD phase, the government selects the best proposal(s) and negotiates a development contract with the contractor(s). More than one contractor may be retained through FSD to maintain the competitive environment of D/V, reduce program risk, or provide multiple production sources, as the acquisition strategy dictates. The purpose of the FSD phase is to provide the design documentation necessary to go to rate production and the ILS documentation necessary to field and fully support the system. This is done by completing detailed design, and by demonstrating that reliability, producibility, supportability, testability, and performance requirements have been met. Continual assessment of risk using technical performance measurement (TPM) and cost schedule control system criteria (CSCSC) is also characteristic of this phase. The FSD design activity is based on the development specifications (Type B) and systems engineering documentation, with such changes as may result from a ratified DCP.

The SEMP is implemented at the beginning of the FSD phase, if not during the D/V phase. Detailed system simulations may be developed to predict system performance and establish specific performance parameters. Plans developed in the previous phases are implemented. Test plans are developed, tests are conducted, and test data are audited and compiled.

A Preliminary Design Review (PDR) is conducted for each CI and normally follows the SDR prior to the start of detailed design. It provides authentication of the development specifications (Type B) and establishes the allocated baseline for CIs. For hardware, the allocated baseline for HWCIs is normally established at PDR, but no later than Critical Design Review (CDR). For software, however, the Software Specification Review (SSR) provides authentication of the software development specifications (Type B-5) and establishes the allocated baseline for CSCIs. The SSR also follows the SDR, but may occur before or after the hardware PDR depending on the amount of effort required to authenticate the software specifications. In any case, the SSR will be conducted prior to the software PDR.

A Critical Design Review (CDR) is conducted for each CI before the design is released for production as a developmental item. Systems engineering activities change considerably in nature after CDR and consist primarily of resolving interface compatibility problems and solving technical problems discovered during development testing. Following the CDR, a Test Readiness Review (TRR) is held for CSCIs to review the contractor's readiness to begin formal CSCI testing in accordance with the software test procedures (Hardware doesn't conduct such a review, but should highly consider doing so). Systems engineering activities also include auditing engineering documentation (drawings and specifications), auditing system test activities (test procedures, set-ups, and

data), configuration control activities, and completion of the verification process.

The FSD phase provides verification of operational effectiveness and suitability before deployment by testing the system or equipment in its intended operational and support environment. The test results are evaluated in reviews and audits intended to confirm that the system design is sufficiently mature to proceed with production and support activities that initiate operational use.

A Functional Configuration Audit (FCA) is conducted on each CI before Milestone III. The CI must represent the configuration released for production, and demonstrate compliance with the development specifications (Type B). Each CI is also subjected to a Physical Configuration Audit (PCA). The PCA may be accomplished in the FSD phase, but is usually done in the beginning of the Production phase on the first deliverable CI that is built on production tooling. Once it has been established that each production article is built in accordance with the product specifications (Type C), the PCA is complete. After PCAs for all the CIs are completed, a system level PCA is accomplished and the product baseline for the system is established. A system Formal Qualification Review (FQR) using operational testing and evaluation information is held at the end of the FSD phase or at the earliest time that adequate test results become available.

The output of FSD is a tested design that meets contract requirements and the documentation necessary to enter the Full Rate Production/Deployment (P/D) and the Operation and Support (O/S) phases. Included are the product, process, and material specifications (Types C, D, and E); Production Plan; ILSP; CRLCMP; and an RFP for the Production phase. Leader and follower contractors are selected and second source qualification procedures are established as called for by the program's acquisition strategy. Each program requires a DCP update and SSARC review. A DAB review also occurs if the production decision has not been previously delegated to the service or if Milestone II cost thresholds are exceeded.

2.3.5 Production/Deployment Phase

The primary objective of the Production phase is to produce and deliver an effective, fully supported system at an optimal cost. In a production run where many items are to be delivered, manufacturing is usually accomplished in two segments. The first segment starts with low-rate production of initial product batches or blocks. During the second segment, the rate increases to peak rate production as necessary changes resulting from initial operational use, experience, review, audits, testing, and production experience are incorporated.

2.3.6 Operation and Support (O/S) Phase

The O/S phase starts with deployment of the system and continues until disposal (which marks the end of the system life cycle). The major activities during this period include introducing modifications and product improvements as necessary throughout deployment as well as supporting the fielded system with items such as tools, spare parts, and technical documents.

2.4 REFERENCES

1. DoDD 5000.1, "Major and Non-Major Defense Acquisition Programs", 1 Sept 87.

2. DoDI 5000.2, "Defense Acquisition Program Procedures", 1 Sept 87

3. MIL-STD-490A, "Specification Practices", 4 Jun 85.

4. MIL-STD-499A, "Engineering Management", 1 May 74.

5. OMB Circular A-109, "Major System 2. DoDI 5000.2, "Defense Acquisition

6. OFPP Pamphlet No. 1, "Major System Acquisitions, A Discussion of the Application of OMB Circular No. A-109".

7. MIL-STD-1521B, "Technical Reviews and Audits for Systems, Equipments, and Computer Software", 4 Jun 85.

CHAPTER 3

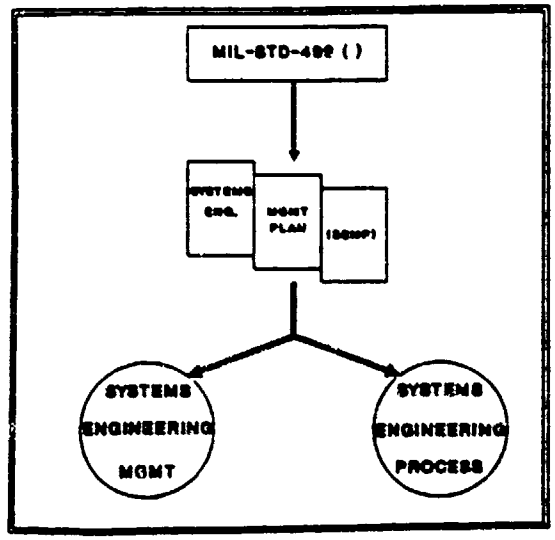
SYSTEMS ENGINEERING MANAGEMENT PLAN

3.1 INTRODUCTION

The basic plan governing the systems engineering effort is the System Engineering Management Plan (SEMP). The SEMP is a concise top level technical management plan for the integration of all systems engineering activities. Systems engineering, basically composed of two components, systems engineering management (SEM) and the systems engineering process (SEP), is implemented through the SEMP. Figure 3-1 depicts the basic relationship between the SEMP and the SEM/ SEP activities.

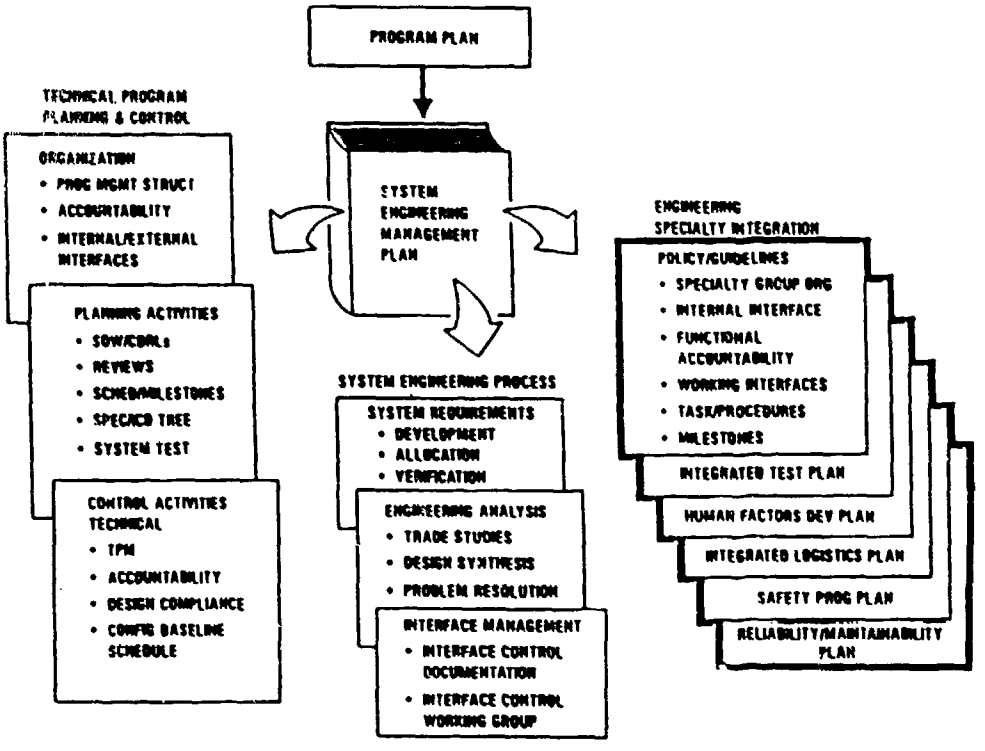
The purpose of the SEMP is to make visible the organization, direction and control mechanisms, and personnel for the attainment of cost, performance, and schedule objectives. The who, what, when, where, how, and why of the systems engineering activities, including information on relevant interfaces and engineering specialty areas, must be clearly delineated. As such, the SEMP is supported by a number of engineering specialty plans, illustrated in Figure 3-2, that describe the technical activities for each of these critical areas. The principal role of the SEMP, therefore, is use as a management tool in identifying and assuring the control of the overall systems engineering process.

The SEMP should be the primary document used in evaluating a contractor's technical proposal. As a minimum, it should 1) reflect the engineering management procedures/ practices of the contractor; 2) define the system/ subsystem integration requirements for the interfaces and their



SYSTEMS ENGINEERING MANAGEMENT PLAN

Figure 3-1



SYSTEMS ENGINEERING MANAGEMENT PLAN

Figure 3-2

relationships with the engineering specialties, discussed in Chapter 4 of this guide; and 3) reflect tailoring of documentation and technical activities to meet program peculiar requirements.

3.2 CONTENT OF THE SEMP

MIL-STD-499A [1] was developed to assist in defining the systems engineering effort in support of DoD acquisition programs. It stipulated that a SEMP shall be submitted as a separate and complete entity within the contractor's proposal describing how a fully integrated engineering effort will be managed and conducted. SEMPs may use the standard format defined found in MIL-STD-499A [1], or, if accepted by the government Program Manager (PM), any contractor proposed format which provides all necessary information. The standard format has three parts: Part I, "Technical Program Planning and Control"; Part II, "Systems Engineering Process"; and Part III, "Engineering Specialty Requirements". Data item description (DID), DI-S-3618/ S152 [2], describes the format, content, and preparation instructions for a SEMP to satisfy MIL-STD-499A [1] requirements. It should be noted that this DID is based on MIL-STD-499 and has not been updated to the format defined in MIL-STD-499A [1].

Some tailoring of the DID is necessary before including it in the Contract Data Requirements List (CDRL); however, DID, UDI-E-23974 [3] should be used when a contractor proposed SEMP format is acceptable. In any case, a typical SEMP should contain the information listed in the sample format of Figure 3-3.

3.2.1 Technical Program Planning and Control

Part I, "Technical Program Planning and Control", describes the contractor's proposed process for the planning and control of the engineering efforts for the system's design, development, test, and evaluation. It identifies: 1) the contractor's organizational responsibilities and authority for SEM; 2) the contractor's control of subcontracted engineering, verification, configuration management, and technical document/ data management; and 3) the proposed plans and schedules for technical design and program reviews. The following is a list of recommended areas to be addressed in Part I of the SEMP:

a. Program Risk Analysis

b. Engineering Program Integration

c. Contract Work Breakdown Structure

d. Assessment of Responsibility and Authority

e. Program Reviews

f. Technical Design Reviews

g. Technical Performance Measurement

h. Interface Control

i. Documentation Control

j. Plan for other technical and program management tasks.

3.2.2 System Engineering Process

Part II, "Systems Engineering Process" describes the contractor's proposed systems engineering process used in defining the system design and test requirements. This part explains the contractor's intended strategy for generating multiple alternative designs at each development level, and the trade-off results which trigger iteration of the system design process. It shall include the 1) specific tailoring of the process to the requirements of the system; 2) procedures to be used in implementing the process; 3) trade study methodology; 4) types of mathematical or simulation models to be used for system and cost effectiveness evaluations; 5) generation of specifications; and 6) generation of applicable engineering documentation. The following is a list of elements of the systems engineering process to be addressed in Part II of the SEMP:

a. Functional Analysis

b. Requirements Allocation

c. Trade Studies

d. Design Optimization/ Effectiveness Analysis

e. Synthesis

f. Technical Interface Compatibility

Systems Engineering Management Plan

Title Page

Introduction

Part 1 Technical Program Planning and Control
- 1.0 Responsibilities and Authority
- 1.1 Standards, Procedures, and Training
- 1.2 Progam Risk Analysis
- 1.3 Work Breakdown Structures
- 1.4 Program Reviews
- 1.5 Technical Reviews
- 1.6 Technical Performance Measurements
- 1.7 Change Control Procedures
- 1.8 Engineering Program Integration
- 1.9 Interface Control
- 1.10 Milestones/ Schedule
- 1.11 Other Plans and Controls

Part 2 Systems Engineering Process
- 2.0 Mission and Requirements Analysis
- 2.1 Functional Analysis
- 2.2 Requirements Allocation
- 2.3 Trade Studies
- 2.4 Design Optimization/ Effectiveness Compatibility
- 2.5 Synthesis
- 2.6 Technical Interface Compatibility
- 2.7 Logistic Support Analysis
- 2.8 Producibility Analysis
- 2.9 Specification Tree/ Specifications
- 2.10 Documentation
- 2.11 Systems Engineering Tools

Part 3 Engineering Specialty/ Integration Requirements
- 3.1 Integration Design/^Plans
  - 3.1.1 Reliability
  - 3.1.2 Maintainability
  - 3.1.3 Human Engineering
  - 3.1.4 Safety
  - 3.1.5 Standardization
  - 3.1.6 Survivability/ Vulnerability
  - 3.1.7 Electromagnetic Compatibility/Inteference
  - 3.1.8 Elecromagnetic Pulse Hardening
  - 3.1.9 Integrated Logistics Support
  - 3.1.10 Computer Resources Life Cycle Management Plan
  - 3.1.11 Producibility
  - 3.1.12 Other Engineering Specialty Requirements/Plans
- 3.2 Integration System Test Plans
- 3.3 Compatibility with Supporting Activities
  - 3.3.1 System Cost Effectiveness
  - 3.3.2 Value Engineering
  - 3.3.3 TQM/ Quality Assurance
  - 3.3.4 Materials and Processes

Typical SEMP Format
Figure 3-3

g. Logistics Support Analysis

h. Producibility Analysis

i. Generation of Specifications

j. Other Systems Engineering Tasks

3.2.3 Engineering Specialty Integration

Part III, "Engineering Specialty Integration" describes the contractor's proposed efforts to integrate the requirements of the engineering specialties, such as reliability, maintainability, human engineering, producibility, survivability/ vulnerability, electromagnetic interference/ compatability (EMI/EMC), safety, electromagnetic pulse hardening (EMP), logistics engineering, environmental considerations, and other areas into the mainstream system design effort. It will include a summary of each of the specialty programs and cross reference the individual plans covering such specialty programs. This part shall depict the integration of the specialty efforts and parameters into the systems engineering process and show their consideration during each iteration of the process. When the specialty programs overlap, the SEMP shall define the responsibilities and authorities of each.

3.3 IMPLEMENTATION OF THE SEMP

MIL-STD-499A [1] requires that an approved SEMP be implemented with the award of the Full Scale Development (FSD) contract. The SEMP should be reviewed as a part of the FSD source selection process, modified during negotiations, and implemented contractually at the earliest possible date. However, some of the most critical systems engineering activity will have been completed before that time and a PM cannot reasonably wait to gain visibility into a contractor's systems engineering methods. There are several ways for the PM to improve visibility during the early phases of the program. Keep in mind, however, that (1) contractors have their own unique set of business standards/ procedures; (2) contractors have their own version of a system concept; (3) the acquisition strategy for each program is different and that the contractors utilized in the Concept Exploration/ Definition (C/E) phase may not even be considered for the FSD effort; and (4) all programs do not necessarily start with the C/E phase, but may start with the Concept Demonstration/ Validation (D/V) or FSD phase of the acquisition life cycle. In other words, each program has its own peculiar set of requirements and the PM must structure the development, delivery, and implementation requirements for a SEMP accordingly.

Generally speaking, the government should review each offeror's systems engineering performance on previous comparable programs and evaluate the offeror's plan for control and execution of C/E phase systems engineering tasks as a part of the C/E phase source selection process. A task can be included in the C/E phase statement of work (SOW) to require the contractor to generate an initial draft SEMP for the program as an end-of-phase deliverable. This plan is intended to be general in scope and to contain only essential details regarding timing and approval of major technical management documentation.

Since contractors will need a SEMP for internal use to execute staffing, organization, and analysis tasks in establishing their D/V effort requirements, the delivery of such a document for government review would not add significantly to the C/E phase effort.

The government may elect to use the initial draft SEMPs as part of the source selection for the D/V phase contract or may require an updated version of it to be delivered as part of the D/V proposal. In either case, the SEMP should reflect, in detail, how the contractor plans to control the systems engineering activities during D/V. When the D/V phase will include major or potentially permanent design efforts, the SEMP should be delivered, reviewed, and approved by the government PM, and implemented through a D/V phase contract modification or option execution, before this design activity begins. The PM may also require expansion of the SEMP into a formal standard format (DI-S-3618/S-152 [2]) or an approved contractor format (UDI-E-23974 [3]) SEMP. Recognizing that a formal standard format SEMP will usually be required in FSD proposals, delivery in that format during D/V may result in savings on the total contractor administrative effort.

As stated previously, the SEMP is required to be approved prior to or in conjunction with the commencement of FSD activity. For competitive acquisition, each contractor will develop and implement their own unique SEMP. The SEMP, which may be used during any phase, should include any update plans specifying which sections must be kept current, who will submit and review changes, and on what dates or in association with what program milestones the updated editions will become effective.

3.4 RELATED PLANNING EFFORTS

Additional plans for the engineering specialties should be referenced in Part III of the SEMP. The need for separate engineering specialty plans is a key part of the acquisition streamlining effort. Where separate engineering specialty management plans are not prepared, often much of the basic information and work will be described in the overall SEMP. Some of the engineering specialty plans which are normally integrated under the systems engineering umbrella are listed below:

a. Technical performance measurement

b. Producibility

c. Maintainability

d. Quality

e. Human engineering

f. Safety

g. Logistic support analysis

h. Reliability

i. Production engineering

j. Contamination and corrosion control

k. Parts, materials, and processes control

l. Electromagnetic control

m. Nuclear hardening

n. Vulnerability/ survivability

o. Weight control

p. Mass properties control

q. Packaging, handling, storage, and transportation.

Where engineering specialty plans are required, they must clearly indicate how the specialty contributes to and benefits from the general systems engineering process and documentation. These detailed plans also provide the initial basis for the development and review of program cost estimates and schedules. Although each specialty plan will probably have its own DID, all plans should, at a minimum, contain the following systems engineering interface information:

a. Objective - Purpose of including the specialty and the scope of its role within the systems engineering process

b. Activity Definition - Summary description of all tasks required to fulfill the specified function, the content of required inputs from systems engineering, and the expected products to be provided to systems engineering

c. Responsibilities - Definition of all organizations supporting (or supported by) the activity, which tasks they are responsible for, and their lines of authority, with particular emphasis on the division of analytical tasks between the systems engineering organization and the specialty organization

d. Schedules - Timing and sequence of all engineering tasks related to major milestones for system development and design, and to specific inputs from supporting organizations in the systems engineering process

e. Resource Definition - Identification of specific hardware, software, personnel, and facilities required to complete the engineering tasks according to the schedule and to provide the required support, from this discipline's point of view, to the overall systems engineering process.

3.5 REFERENCES

1. MIL-STD-499A, "Engineering Management"

2. DI-S-3618/S-152, "System Engineering Management Plan (SEMP)".

3. UDI-E-23974, "Plan, Systems Engineering Management (SEMP)".

CHAPTER 4

SYSTEM INTEGRATION

4.1 INTRODUCTION

A Primary role of system engineering is to ensure that the many diverse elements comprising a system are compatible and ready when needed. This avoids the situation in which hardware or software, when integrated into the system, fails to function as intended as part of the system. Integration ensures that all the "pieces" of the system will work together to realize system goals. Proper planning and coordination throughout the development process can ensure that problems are held to a minimum and that the final implementation of the system satisfies the mission performance requirements.

4.2 APPROACH

The basic plan for managing the System Engineering effort is the System Engineering Management Plan (SEMP), which is defined in MIL-STD-499A [1], and is prepared in three parts. Part One, "Technical Program Planning and Control", identifies organizational responsibilities and authority for system engineering management, including control of subcontracted engineering, verification, configuration management, document management, and plans and schedules for design and technical program reviews. Part Two, "Systems Engineering Process", describes the process used in defining and allocating requirements and their documentation. Part Three, "Engineering Specialty Integration", defines how the engineering specialties of reliability, maintainability, human engineering, safety, logistics, and other areas are integrated into the mainstream design effort.

The contractor begins preparing the SEMP in the Concept Exploration/ Definition (C/E) phase, defining how he will structure his organization for the specific program and how he will control the total engineering process to provide a product that satisfies performance requirements. The SEMP will define the models and simulations that are used for defining system requirements and optimizing system configuration. These same models are employed in the verification process, which is also in the SEMP. Appendix A to MIL-STD-499A [1] defines specific tasks to be accomplished under Parts One and Two. These tasks may be tailored depending on the nature of the program.

The SEMP should be program specific and identify the organizational configuration, functions and responsibilities, management techniques, analyses, trade studies, simulations, Technical Performance Measurements (TPM) parameters, and schedules, that will be investigated or employed on the

program. During negotiations and after contract award, the SEMP may be revised to incorporate or delete items the government and contractor agree are suitable. Thereafter, the SEMP provides the basis for all contractor system engineering effort on the program.

During the Concept Demonstration/ Validation (D/V) phase, plans for critical specialty areas are also prepared. These plans are summarized or referenced in Part Three of the SEMP. Where no separate plans are prepared, a summary of the effort is included in the SEMP. All plans should contain the following elements:

a. Objective: Purpose and scope.

b. Activity Definition: Summary description of all tasks required to fulfill the specified function including inputs and nature of outputs.

c. Responsibilities: Definition of all organizations supporting activity, portion of activity for which they are responsible, and line of authority.

d. Schedule of Activities: Time sequence of tasks tied to program schedule milestones, showing inputs from supporting organizations.

e. Resource Definition: Identification of specific hardware, software, and facilities required to perform this activity within the specified time frame.

The level of detail that can be provided in the plans reduces, to a significant extent, the number of problems that will be encountered in performing this activity. In addition, the detail provides a firm basis for the development of program cost and schedules. These plans may include:

a. Reliability Plan

b. Maintainability Plan

c. Human Engineering Plan

d. Safety Plan

e. Contamination and Corrosion Control Plan

f. Parts, Materials, and Processes Control Plan

g. Electromagnetic Control Plan

h. Survivability/ Vulnerability Plan

4.3 ENGINEERING SPECIALTY INTEGRATION

Engineering specialties are those disciplines which support the design process by applying knowledge from a specific area to ensure system operability in its operational environment. They include reliability, maintainability, human engineering, safety, electromagnetic compatibility, parts/ materials/ processes and other specialist areas involved in development of a general class (ships, aircraft, tanks) of system. These specialties are integrated into the development effort through the system engineering process. MIL-STD-499A [1] speaks to this effort as follows:

"System Engineering includes the .... integration of the engineering specialties and

the management of a totally integrated effort of design engineering, specialty engineering, test engineering, and production engineering to ensure their influence on design."

In Section 3.4 of MIL-STD-499A [1], engineering specialty integration is defined as follows:

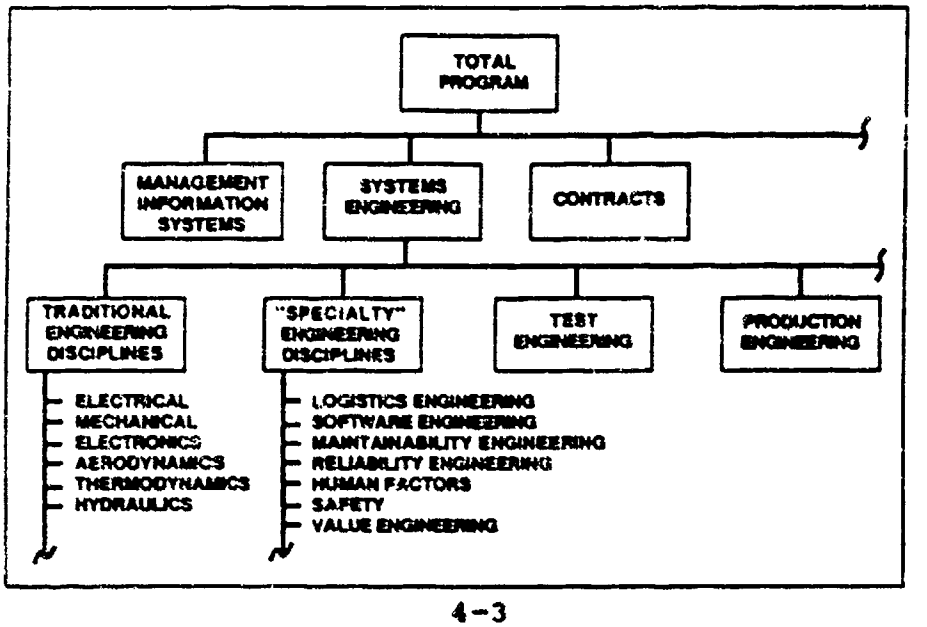
"The timely and appropriate intermeshing of engineering efforts and disciplines such as: reliability, maintainability, logistics engineering, human factors, safety, value engineering, standardization, transportability, etc., to ensure their influence on design."

4.3.1 Integration Framework

A conceptual framework for the discussion of engineering integration is shown in Figure 4-1. It shows a way to categorize the disciplines that participate in the systems engineering process. Although "traditional" and "specialty" engineering are shown in separate branches, both branches are equally important parts of conceptual, preliminary, and detailed design. The categorization simply reflects that, because the design could be accomplished without considering the "specialty" disciplines, special emphasis must be placed on the detailed integration of these efforts. All branches shown are representative but not complete.

The systems engineering process provides a technical management framework for the design team. At any point in the acquisition phase the design team consists of a mix of traditional engineers, "specialty" engineers, test engineers, logistics engineers, value engineers, production engineers, etc. In the earlier stages of the program, the team may be engineers skilled in functional analysis. During full scale deveolpment (FSD), the composition of the team will shift to traditional engineers skilled in traditional engineering design practices and specialty engineers skilled in design support. During late FSD and production phases, the emphasis will shift to a team dominated by production, logistics, and test

Figure 4-1
Engineering Integration in the
Systems Engineering Framework

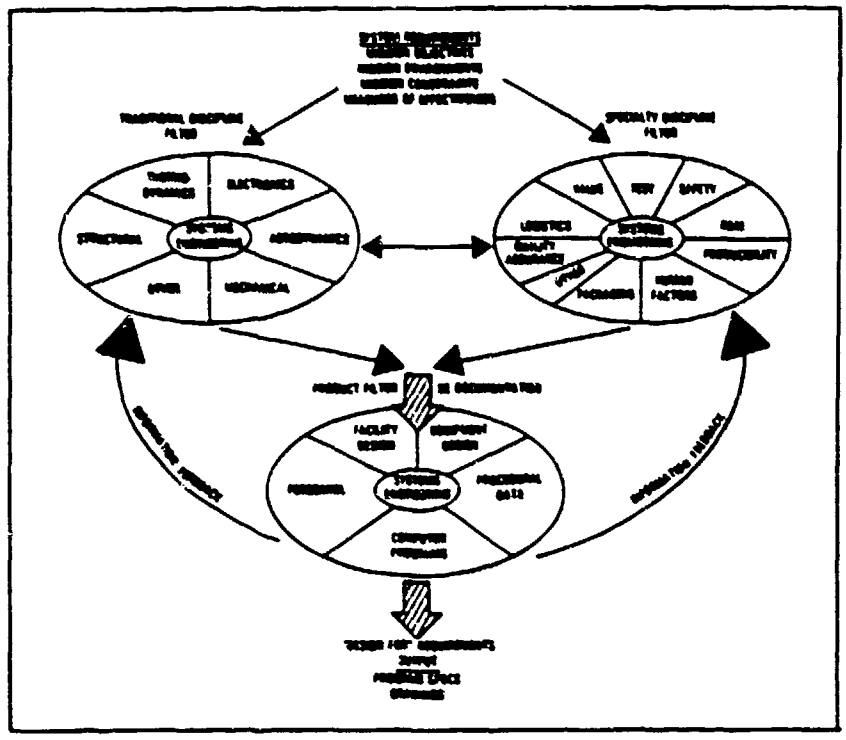


engineers.

The integration of the design process is conceptualized in Figure 4-2. Three integration filters are shown in the overall process. As information is taken into the "traditional discipline filter", emphasis is placed on those traditional design techniques (such as stress analysis of structures) required at a given stage of design (conceptual, preliminary, or detailed design). The traditional design engineers draw heavily on the state of the art technology of their area. At the same time, design documentation is being developed and/ or modified by "specialists" in such areas as reliability, maintainability, and human engineering. The "specialists" are establishing requirements independent of the emerging traditional discipline design, but they are also reviewing and modifying the traditional discipline output. The SEMP would normally contain enough detail to show the timing and format of data which each "specialist" would supply to the systems engineering process. Finally, all requirements are filtered by the unique demands of the products which comprise the system. The requirements are then described by specifications and drawings which set out in clear language the "design-for" requirement. Of course, the diagram in Figure 4-2 is only conceptual, as the design of any product element usually will require several iterations through each process step.

Specialty engineers draw upon an extensive background of data extracted from past and current programs to develop standards, guidelines, and checklists to support and evaluate development of new designs. To maintain proficiency in their specialty area and to

Figure 4-2
Technical Integration Process



ensure rapid communications on new developments and problems, they are permanently a part of the specialty staff and temporarily assigned to programs as the need arises. Depending on the nature of the contractor's organizational structure, these may be separate organizations or they may be grouped under major division. For example, during the early phases of the program up through Preliminary Design Review (PDR) the specialties may report to Systems Engineering. Depending on their function and size within the program, they may then become separate organizations, such as Integrated Logistics Support (ILS).

The more common approach for large system oriented companies is the matrix organization in which personnel are assigned to programs from their "home" organizations for the period they are needed on the program. Within the program, all engineering may be under the responsibility of a chief engineer. In this case the system engineering manager is another of the functional managers (such as mechanical, electrical, software, etc.) reporting to the chief engineer. System engineering is responsible for definition of requirements and interfaces and integration of the hardware and software into the system. The engineering specialties may be grouped in a single organization and report to the chief engineer, or they may be located in the system engineering organization, depending on the size and nature of the program. In either case, the specialists work with system engineering to define and document requirements and work with the functional engineering groups to ensure the necessary specialty features are incorporated in the design. The chief engineer is more typical of established aircraft firms. A different management approach which has arisen over the past decade is that of the Chief Systems Engineer (CSE). The CSE is one of the functional managers reporting to the program manager (PM). The primary role of the CSE is that of defining the requirements and auditing the design. He is the PM's top technical authority and the head of Systems Engineering. Since the engineering specialties perform a similar function, they are usually placed within the systems engineering organization to strengthen their voice in requirements definition and documentation and to ensure a total and complete review of the evolving designs. The role of the specialist under system engineering is to define requirements for design and verification, to audit the resulting design for compliance, and to plan all activities related to their functions. Placement of specialty engineering within system engineering assures that all requirements on the system are identified and uniformly levied and flowed down throughout the system. In addition, it assures the coordination of system audit activities and their uniform application.

Engineering specialists are brought into the design process at a very early stage--in limited numbers during the C/E phase if candidate designs have been developed in sufficient depth to be analyzed and in full complement for the D/V phase. Both the reliability and maintainability engineers are typically among the earliest involved, since they can have the greatest impact on design. The specialists define requirements in their area, typically by tailoring government standards to the specific needs of the program. These requirements are then

placed in specifications. The requirements are both quantitative (e.g., reliability values, and allocations, Mean-Time-to-Repair values, and availability values) and qualitative (by referencing standards, properly tailored in the specification appendices, which specify constraints, procedures, limitations, etc.). Since the top specifications (system and segment) are prepared by systems engineering and lower level ones require their review and approval, this ensures that specialty requirements are incorporated at all specification levels. Specialists also work with program engineering personnel, reviewing and analyzing the evolving design and ensuring the incorporation of necessary features in their area (e.g. redundancy, access areas, Built-In-Test (BIT)).

During the D/V phase, each specialty area prepares plans defining how they will perform tasks in the FSD phase, describing procedures, resources, tasks, and the schedule of activities. Although often identified as separate Contractor Data Requirements List (CDRL) items, these also are also summarized in Part III, Integration of the Engineering Specialties, of the SEMP. The SEMP also discusses how they are integrated and relates the specialty tasks to the overall systems engineering effort.

In all phases, specialists form a part of the systems engineering design review team. Data packages produced by the program engineering organizations are reviewed against established check lists to verify compliance to all specialty area requirements. Deficiencies are documented in action items as part of the meeting minutes and followed up by systems engineering to assure resolution. All change packages are also reviewed by specialty engineers prior to their presentation to the Configuration Control Board (CCB) to ensure that they will have no deleterious effect on the system operability.

Specialty area test requirements are also developed. These may include specific specialty tests such as reliability life tests, EMC/EMI tests, and maintainability teardown tests, as well as the incorporation of specialty area tests into the general component (software and hardware) subsystem, and system level test plans. These form the Test and Evaluation Master Plan (TEMP) which is the responsibility of systems engineering. During development and qualification testing in the FSD phase, test data are evaluated by specialty groups to determine if required standards and levels in their areas have been met. Qualification (at the component level) is certified by reliability engineers based on demonstrated capability to meet specification requirements.

The specialty tasks are performed under the cognizance of the systems engineering manager (or CSE) who directs the requirements derivation and flow down effort, reviews, audits, and system verification effort. As with the performance requirements stated in the system specification, specialty engineering requirements must also be reviewed to ensure that they do not impose an unnecessary burden on the system, but are adequate to allow the system to meet operability requirements. It must be recognized that while the requirements setting and review and audit functions are typical systems engineering activities, specialists are also far more involved in

the detail design and testing than is normal system engineering practice. This imposes a greater burden on system engineering management to assure that the specialists do not "overdrive" the design, i.e., incorporate more features in the design than are cost effective. Typically, the lead engineer or supervisor of the design support group reports directly to the systems engineering manager (or CSE). The supervisor is responsible for integrating the activities of his group and reporting its activities and significant decisions to the manager. He is also responsible for maintaining open communications channels with the "home" system effectiveness organizations to ensure that specialists are alerted to new problems and techniques as they become known and that expert specialty area consultation is available when needed. The manager must ensure that specialty requirements are properly reviewed by the systems engineering staff with regard to their impact on cost, schedule, performance, and operability, and then incorporated into the appropriate documentation. Decisions made by the specialty groups have a major impact on operational costs, which usually constitute the largest portion of system life cycle costs (LCC). Placement of them within system engineering, during at least the initial program phases (when the majority of LCC are being committed), helps ensure that an optimized, cost-effective system will result.

4.3.2 Reliability Engineering

Reliability engineers address the issue of equipment/ system performance by applying analytical methods and historical statistical data. They derive a functional model of system performance in accordance with the design and a mathematical model whose outputs are inherent failure distributions and failure rates. By analyzing the design and applying historical data, an estimate of the probability of successful performance (or failure) is calculated for the system and each segment, subsystem, assembly, and such. Their analysis identifies the strengths and weaknesses of the design so that improvements are made to the best advantage. Therefore, a dynamic communication occurs between design and specialty engineers during concept studies, trade off analyses, design, and development.

One may question the accuracy of such estimates, or in statistical terms, the probability density function. How well does the historical data that were used apply to this system, this design, this mission, and also how many trials, attempts, or missions are represented by the data? Both qualitative and statistical answers might be available, but is advisable to examine the planned testing program to determine if applicable, realistic data will be available to apply to this question, and if the test program could be improved.

Reliability estimates based on the inherent (generic) failure rates are useful for planning purposes, for comparing alternatives, and for assessing proposed changes. Later, when test and operational data are available, they will become the basis for program decisions and actions and a basis for revised reliability estimates.

Reliability engineering tasks include the following:

a. Monitor/ Control of sub-contractors

and Suppliers

b. Program Reviews

c. Failure Reporting, Analysis and Corrective Action System (FRACAS)

d. Failure Review Board

e. Reliability Modeling

f. Reliability Predictions

g. Failure Modes, Effects and Criticality Analysis (FMECA)

h. Sneak Circuit Analysis

i. Electronic Parts/ Circuits Tolerance Analysis

j. Reliability Critical Items

k. Effects of Functional Testing, Storage, Handling, Packaging, Transportation and maintenance

l. Environmental Stress Screening

m. Reliability Development/Growth Test (RDGT) Program

n. Reliability Qualification Test Program

o. Production Reliability Acceptance Test (PRAT).

Descriptions and discussions of these reliability tasks can be found in the Task Section and Appendix A to MIL-STD-785 [2].

The reliability requirements of space and missile systems may differ significantly from ground, flight, or shipboard systems. Space and missile systems are generally maintainable in a readiness mode, but not maintainable in a mission mode. Therefore, the emphasis given to certain reliability tasks can vary.

The reliability program plan is normally submitted as part of the bidder's response to the request for proposal. Unless it is necessary to obtain a detailed plan to evaluate the response, a brief description or preliminary plan may be sufficient. However, a program integrated reliability task schedule and a manhour estimate for each task are necessary.

4.3.3 Maintainability Engineering

Maintainability engineers address the maintenance concept/ policy as it is reflected in design provisions for fault prevention, detection, isolation and correction, and the implementation requirements in terms of skills, test equipment, time to repair/ replace/ restore, and maintenance cost over the life cycle of the product. Maintenance concepts are based on operability considerations and on operations phase support concepts. Maintenance provisions are an important design factor in determining system availability and in life cycle cost. Maintainability specialists translate broad support concepts and requirements into detailed concepts and plans for each item at each level of maintenance: organization, intermediate, and depot. A system maintenance model is used to examine alternative configurations, methods, and test techniques to minimize downtime and maintenance cost and to allocate

requirements to maintainable items. From these analyses both qualitative and quantitative design criteria are established so that design engineers will incorporate maintainability provisions together with configuration and performance in the earliest stages of design. As design details emerge, reliability specialists provide estimates of maintenance frequency- mean time between maintenance (MTBM) for the maintainable items, and maintainability specialists determine the restoration times (MTTR), the direct manhours per maintenance action (DMH/MA), and the maintenance manpower cost for each item and for the system. These are compared to the item allocations and system requirements. Where discrepancies exist, they may require reallocation of requirements or a design modification to meet specification. Results are reported to reliability engineers and other specialists as well as personnel involved in life cycle cost (LCC), design to cost (DTC) and integrated logistic support (ILS). Similar tasks and results are necessary for subcontract and government furnished items. Maintainability engineers must actively interface with human engineering, test equipment design (testability, skills, fault isolation), system safety (hazards, critical items), manufacturing (repair time), and others to realize an effective, optimized system design.

System failure diagnosis, fault isolation, removal, replacement/repair and retest or verification times are difficult to estimate. Therefore, maintainability demonstration tests may be necessary to obtain useful estimates. Maintainability specialists plan and direct these tests as required in accordance with MIL-STD-470 [3].

The maintainability program plan is normally submitted as part of the bidders' response to the procuring activity's request for proposals. In many instances, a brief preliminary plan is sufficient for proposal purposes, provided a program integrated maintainability task schedule and a manhour estimate for each task are submitted.

4.3.4 System Safety

Safety specialists analyze the system/ program for hazards to personnel and equipment and take action to eliminate or control them. Safety concerns encompass all personnel and equipment which may be affected by program plans and operations. These include, but are not limited to manufacturing, testing, packaging, handling, transportation, storage, and government personnel and equipment at launch, test, and operational sites. Local, state, and federal laws and regulations that are designed to protect employees and the general public alike are involved, as well as specific safety requirements of the equipment or the design.

Safety specialists apply formal methods of hazard identification and analysis, develop design criteria, review the design for compliance, and provide safety certification of the equipment/ system for the readiness review. Safety requirements and standards are applied to all operations by performing an Operational Hazard Analysis (OHA) and reviewing plans and procedures. Safety critical items and operations are identified and controlled to reduce hazards to an acceptable level of risk. During safety critical operations, safety specialists are on-site to assure that safe procedures and methods are used and

to assist operations personnel as necessary.

When quantitative safety requirements are used, fault tree analysis is employed to establish combinations of modes or conditions that produce hazards, combinations of contributory events, and the probability that the undesired event will occur. Fault tree analysis shows in tree form the paths which could lead to a hazardous condition as these various occur. A probability is usually assigned at each junction. Lessons learned from previous developments are of paramount importance to safety. Extensive records of accident reports, safety publications, analysis reports, failure and corrective action reports, safety surveys, audits, and design reviews are required. An Accident Risk Assessment Report (ARAR) may be prepared to identify design and operating limits to be imposed on system elements to preclude or minimize mishaps which could cause injury or death. System safety program requirements are selected from MIL-STD-882. A detailed list of system safety program requirements for each of the life-cycle phases is provided in MIL-STD-882 [4], paras 4.2.1 through 4.2.4.

4.3.5 Parts Engineering

Parts are the building blocks of equipment and systems. The inherent or generic failure rates of parts and the design application of parts will principally determine failure frequency, readiness, mission success, maintenance costs and logistic support costs. Parts which are similar functionally are available with a wide range of inherent failure rates (e.g., 10^{-2} failures per 1000 hour to 10^{-6} failures per 1000 hour). Depending upon the parts selected, a system of 1000 parts may have a mean time between failure (MTBF) of 100 hour or 100,000 hour. Established, reliable parts with the best available failure rates cost more to manufacture and test than commercial parts, so the initial cost is higher, but system life cycle cost may be significantly lower. Parts are derated (applied to the design at levels well below maximum ratings; e.g., voltage, current, and temperature) to reduce the risk failure.

Early in program, parts specialists establish the Program Parts Selection List (PPSL), which designers use to select standard parts that meet program qualification, documentation, and reliability requirements. If the design requires parts not previously qualified, documented, or without adequate performance history, then these additional tasks and tests must be planned and completed. Coordinated standards and coordinated procurement of parts between contractors and subcontractors may be required to reduce purchase costs or improve lead time.

A Parts Control Board (PCB) may be required to control the parts program. The PCB is composed of parts control engineers and reliability engineers reporting to systems engineering, program design engineers, and product assurance engineers. They establish the PPSL, review and approve proposed additions, and define parts testing requirements and qualification criteria. The PCB also defines criteria for subcontractors and in-house testing of parts, documentation of parts manufacture, and in-process monitoring and reporting of parts assembly lines. The latter may include certification of operators and inspectors, destructive physical analysis on selected samples,

protection of sensitive surfaces, inspection requirements, and traceability implementation.

Parts control program requirements are selected from MIL-STD-965 [5]. In many instances it may be necessary to complete certain trade studies on performance, reliability, logistics, and life-cycle cost before the parts requirements can be determined. The parts program for the C/E and D/V phases may be the basis for developing a more specific parts program for the FSD, Production and Deployment/Operations phases.

4.3.6 Human Engineering

Human engineering specialists address the people-equipment interface. They apply principles of human capability to reach, lift, see, communicate, comprehend, and act to the functions and circumstances required. They are another team member in the design process whose goal is to optimize the system. They first allocate system functions to personnel, equipment, software, or facilities. The level of involvement and criticality of personnel tasks are identified. Human factors engineers then use task analysis and time line studies to determine if human capabilities will be exceeded. They prepare models and mock-ups to evaluate alternative designs or concepts and for dynamic simulation of critical human performance. Human engineering specialists work with design, system safety, maintainability, testing, training production, subcontractors, deployment, logistic support, and operations personnel. The protection of personnel from hazardous environmental conditions is an important consideration on which they help focus program attention. Human engineering program requirements are usually selected from MIL-STD-46855 [6] or MIL-STD-1472 [7].

4.3.7 Electromagnetic Compatibility and Electromagnetic Interference

Unintentional electromagnetic radiation can cause unacceptable degradation (interference to electronic equipment within range or initiation of electroexplosive devices). EMC is achieved by eliminating or controlling unintentional radiation to an acceptable level or by shielding equipment from its effects. Protection from lightning and static charges are included in this discipline.

EMC/EMI specialists address electromagnetic sources of radiation within the system such as: motors, generators, power sources, signal and power wiring, transformers, relays, etc. They develop design criteria to minimize potential radiation shielding, bonding, lead lengths, wire routing, component placement, and de-coupling. It is usually necessary to perform a detailed analysis of the electrical power system to determine power bus characteristics and dynamic impedance and to evaluate any undesirable steady state or transient effects. Development and qualification tests include EMC/EMI tests to measure unintended radiation and its effects.

Requirements for EMI characteristics of equipment are set forth in MIL-STD-461 [8]. An EMC control plan provides policies, guidelines, methods, and tasks required to achieve the characteristics required. The plan is usually prepared in

accordance with MIL-E-6051 [9] for systems.

4.3.8 Contamination and Corrosion Control

Several types of manufact-uring require contamination control. Semi-conductors, microelectronics, precision bearing, and such require atmospheric control of airborne particles and control of surface contaminants. Equipment applications and environments may require moisture, fungus, and corrosion prevention techniques in design, manufacturing and surface protection. The advent of space systems and the Space Transportation System has resulted in system application requirements for contamination controls which far exceed other system applications in complexity and mission critical consequences. Ultra-cleanliness is important, but in addition, space induced and operationally induced contaminants are critical to instruments and optics. Outgassing of materials, volatile condensable materials, and the output of upper stage propulsion devices, for example, are some of the contaminants which have to be controlled.

Military equipment operates under the most difficult environments imaginable. Extremes of temperature, humidity, sand, dust, salt spray, rain, all tend to debilitate equipment rapidly. Without proper resistance or protection, much equipment would cease to function, or fail to function when called upon. Protection must be provided by the proper specification of materials, covers and seals, packaging, heating and cooling devices, or other design features which permit extended storage and operation throughout the range of operational environments. Once a qualification unit has been built, it must be subjected to tests which encompass the full range of environmental requirements, plus a margin of safety.

4.3.9 Survivability/ Vulnerability

Military systems are vulnerable to the natural environment of ground or space and to hostile threats from ground forces, air forces, and anti-satellite weapons or nuclear detonations. Engineering specialists in survivability/vulnerability analyze and evaluate these natural and induced threats in the C/E phase to determine the design approach and methods required to meet survivability requirements in the system specification.

These specialists analyze the vulnerability of the system in terms of the capability of parts and materials, protective measures, system architecture, functions, and controls. Risks and alternatives are assessed in tradeoff studies which lead to design criteria and decisions necessary to reduce vulnerability and improve survivability.

A survivability issue of concern to many ground-, air-, and space-based systems is that of electromagnetic pulse (EMP), one of a number of nuclear weapons effects that must be considered in a hardening program. EMP is a burst of radio frequency energy whose time signature and spatial extent depend on the height and location of a nuclear burst relative to the point of observation. The EMP generated wave form generally bears little resemblance to the conducted transient energy that arrives at a point of entry to electronic equipment. Hardening a system to EMP entails: determining the

external threat environment and the coupling of the environment to the system to determine the energy pulse at the electronic equipment, preparing survivability specifications for that equipment, determining the methods of protecting that equipment, selecting the analysis and/or test techniques to verify the hardening approach, and specifying the techniques to assure and maintain the hardness of the equipment when produced and placed in service.

4.4 HARDWARE/ SOFTWARE INTEGRATION

Although nor normally considered an engineering specialty, hardware/ software integration is a critical and unique function in ensuring the quality of a product. In order to provide the system perspective required to successfully accomplish its tasks, this group is located within a system engineering department. It consists of individuals having both computer hardware and software backgrounds and possessing a good understanding of system configuration and operation. Systems engineering has four basic responsibilities with respect to software development: 1) definition of the system level design approach, 2) analysis and allocation of system requirements to hardware and software configuration items, 3) definition of the interfaces between hardware and software configuration items, and 4) performance of technical reviews and audits.

Systems engineering specifies and approves requirements allocated to each computer program and audits programs to verify compliance with these requirements. In addition, systems engineering provides interface requirements and characteristic input data to the software development personnel and verifies the successful integration of equipment and computer programs. Systems engineering also performs assessments of the computer software use, of computer timing and storage resources, and the status of technical progress.

Systems engineering is responsible for conducting design reviews, for internal contractor approval of software configuration changes (prior to submission for government approval), and for certifying that development milestones are satisfied. Systems engineering also works with the test organization to verify the proper functioning of all computer programs, the proper integration of and nominal execution of hardware and software, and the satisfactory demonstration of system operation over the total range of specified operating conditions (normal and abnormal).

The primary instrument of hardware/ software integration is the hardware/ software Interface Control Document (ICD). The ICD is required to specify the functional interface between the computer program product and any equipment hardware with which it must operate. It is often true that supplier documentation for standard computer peripherals and terminals is adequate for this purpose. Conversely, it has been found that performance specifications governing the design new equipment is not satisfactory for use as a functional ICD. The purpose of an ICD is to communicate equipment interface requirements to programmers in terms that the programmers readily and accurately understand and to require equipment designers to consider the

Figure 4-3
Sample Format of an
Interface Control Document (ICD)

1.0 **Scope:** Purpose and coverage
2.0 **Applicable documents:** List of all documents referenced in Sections 3 and 4
3.0 **Requirements**
3.1 **Physical Interface**
3.1.1 **Mechanical Requirements:** Envelope, attachment, obscuration, alignment
3.1.2 **Master Tooling**
3.1.3 **Mass Properties:** Weight, moment-of-inertia, center-of-gravity location, axes, models exchange (math/physical)
3.2 **Electronic Interface**
3.2.1 **Command Signals:** Format, rates, identification
3.2.2 **Data signals:** Radio frequency characteristics, format, rate
3.2.3 **Telemetry Signals:** Format, clock, identification, recording
3.3 **Electrical Interface**
3.3.1 **Electrical Power:** Type, voltage, power profile, protection
3.3.2 **Interface Pin Assignments**
3.3.3 **Electromagnetic Compatibility**
3.4 **Hydraulic/Pneumatic Interface:** Type, flow rate, temperature, pressure
3.5 **Software**
3.5.1 **Data:** Inputs, outputs, rates, accuracies
3.5.2 **Messages:** Format, content, storage
3.5.3 **Protocols:** Enable, processing, validation, error detection, recovery
3.6 **Hardware/Software**
3.6.1 **Interface:** Diagrams, standards, and conventions
3.6.2 **Timing and Sequencing:** Control and logic, relationships, data transfers, input sensing
3.7 **Environmental**
3.7.1 **Structural:** Vibration, shock, acoustic, loads, dynamic mode shapes
3.7.2 **Thermal:** Temperature range, heating rates, heat transfer surfaces
3.7.3 **Magnetic:** Flux density, rate-of-change
3.7.4 **Radiation:** Type, flux density, total dose
3.7.5 **Ambient:** Pressure, temperature, containments
3.7.6 **Air Conditioning:** Temperature, flow rates
3.8 **Safety**
3.9 **Operational Limitations**
4.0 **Verification**
4.1 **Quality Assurance**
4.1.1 **QA Requirements**
4.1.2 **ICD Requirements Verification:** Matrix
4.2 **Factory Tests**
4.2.1 **Facility Requirements**
4.2.2 **Receiving Inspection**
4.2.3 **Installation Requirements**
4.2.4 **Test Constraints**
4.2.5 **Test Sequence**
4.2.6 **Shipping Preparation**
4.3 **Launch Base Tests**
Appendix: Delivery Schedules

impact of their design on computer programs.

The ICD provides an exact definition of every interface, by medium and by function, including input/output control codes, data format, polarity, range, units, bit weighing, frequency, minimum and maximum timing constraints, legal/illegal values, and accuracy, resolution, and significance. A sample ICD format is provided in Figure 4-3. Existing documentation may be referenced to amplify explanations of the effect of input/output operations on external equipment. Testing required to validate the interface designs is also specified.

4.5 INTERFACE MANAGEMENT

Precise interface definition early in the program is essential to a successful and timely development. Using functional analyses, systems engineering develops functional and interface requirements. As the total system is "decomposed" into functional areas, interfaces between the areas appear. These may be physical or operational (or both), but are usually characterized by mechanical, electrical, or functional data parameters or procedures with associated data requirements. Functional and performance interface requirements are contained in the appropriate segment or (CI) specifications. However, the design implementation of these requirements must be defined to all concerned in order that the equipment, when developed and integrated, will function satisfactorily.

Interfaces are initially defined through the use of functional flow block diagrams and functional interface input/output charts. These tools primarily define the flow data. Once the functional requirements have been completely allocated the design implementation of the interfaces can proceed. This often involves a number of contractors and organizations that require close coordination by system engineering to ensure compatibility of all interfaces. Interface development is accomplished through the use of Interface Control Working Groups (ICWGs). These ICWGs are generally organized by the prime contractor or system integrator, if the latter is used on the program. The government PM may chair these groups, although it is often done by the prime contractor, with the government being co-chairman to ensure resolution of any conflicts that may arise between associate contractors. The ICWGs may be divided into interface panels that handle specialized areas such as EMC, computer resources, and test planning. The chairman is responsible for organizing the groups, ensuring that the proper specialties are supported by individuals who have authority to commit their organizations or who are charged with obtaining their organizational approval for ICDs done by the ICWG. The chairman also prepares the agendas, conducts the meeting, prepares minutes of the meeting, takes action items, and assigns responsibilities. The prime contractor ensures that action items are completed and that the responses are properly documented and transmitted to those parties involved in the design implementation.

The results of this activity are documented in ICDs. The nature of the ICD varies considerably, a radio frequency depending on the interface being documented. It can be a physical, an RF,

or an operational interface as illustrated in Fig. 4.4 for a space system. Design definition takes the forms of drawings, schematics, function lists, data format diagrams, operational procedures, equations, and any other data required by the designers to completely detail their design. Electrical circuitry, for example, is usually defined to include the first active circuit on either side of the interface. The ICD does not duplicate the specification, rather it describes the design implementation of the requirements in the specification.

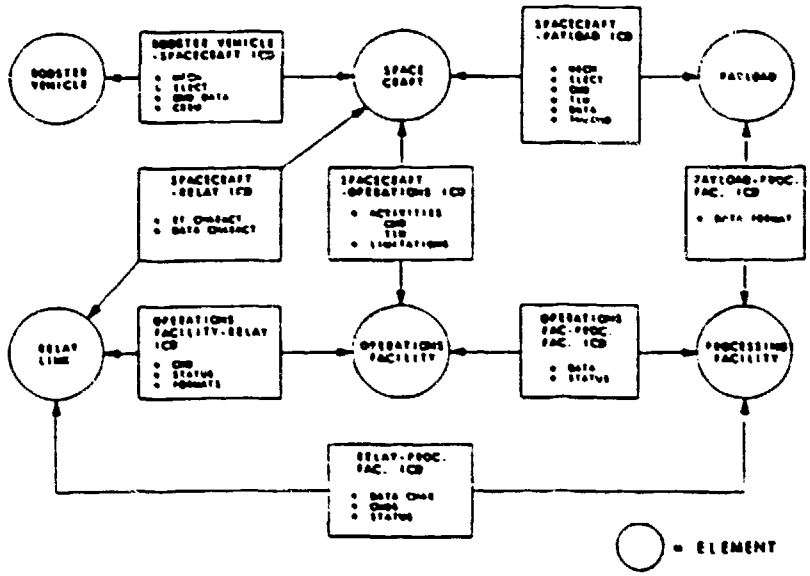
The ICD outline is prepared by the prime contractor and portions are assigned to parties responsible for the development of the interface. Following completion of the ICD, it is signed by all parties involved in the interface and placed under configuration control. The ICD then has the same status as a specification in that it represents the baseline configuration, and any changes must be acted upon by the appropriate CCB. A number of CCBs may be involved in implementing the change, including those at the interfacing contractors and the Government Program Office, which must approve any changes to the segment interfaces.

4.6 SUMMARY

Integration of design requirements is part of the system engineering process, whether "designing-for" performance/constraints associated with traditional, specialty, or product oriented disciplines. Each discipline "filter" is integrated within the basic systems engineering process steps of functional analysis, synthesis, and evaluation/ decision. All disciplines share common systems engineering documentation which they use to express requirements. The rigor imposed by a formal systems engineering process ensures that all of these specialty disciplines respond to requirements in a

Figure 4-4

Typical Space System Interface Control Documents



timely, integrated manner by providing a basic model for the activities which must be accomplished in the systems engineering effort and an integrated data system for development and integration of system requirements.

Figure 4-5 presents some general task descriptions for an engineering process. The figure lists tasks that engineering personnel should undertake in a development program using systems engineering as a technical management tool. No particular discipline is identified by each task since most disciplines must 1) accomplish planning, 2) identify and allocate functional requirements, 3) participate in trade studies, 4) provide inputs to the documentation, and 5) participate in design reviews. The specific timing of these efforts is itself the subject of analysis and trade-offs by the systems engineering function, and must be uniquely described in the SEMP as well as all associated "specialty" plans. Often integration is partially achieved using common data formats. Figure 4-5 illustrates how systems engineering documentation is used to support tasks which contribute to the integration of engineering disciplines in each life cycle phase. In this figure, where a relationship between a task and a documentation form is indicated, a potential use of the documentation in support of the task is suggested. Where no relationship is shown, no specific form is related to the integration task.

4.7 REFERENCES

1. MIL-STD-499A, "Engineering Management".

2. MIL-STD-785, "Reliability Program for System and Equipment Development and Production".

3. MIL-STD-470, "Maintainability Program Requirements for Systems and Equipment".

4. MIL-STD-882, "System Safety Program Requirements".

5. MIL-STD-965, "Parts Control Program".

6. MIL-H-46855, "Human Engineering Requirements for Military Systems, Equipments and Facilities".

7. MIL-STD-1472, "Human Engineering Design Criteria for Military Systems, Equipment and Facilities".

8. MIL-STD-461, "Electromagnetic Emission and Susceptibility Requirements for Control of Electromagnetic Interference".

9. MIL-E-6051, "EMC Requirements, Systems".

Figure 4-5 (1 of 4)
Principal System Integration Tasks

PHASE PRINCIPAL SYSTEM INTEGRATION TASKS	PRIMARY SE DOCUMENTATION INTERFACE											PRINCIPAL MIL SPEC/STD	PRIMARY SPECIFICATION INTERFACE			
	FUNCTIONAL FLOW BLOCK DIAGRAM (FFBD)	END ITEM MAINTENANCE SHEET (EIMS) LOGISTIC SUPPORT ANALYSIS	TEST REQUIREMENTS SHEET (TRS)	PRODUCTION SHEET (PS)	REQUIREMENTS ALLOCATION SHEET (RAS)	TIME LINE SHEET (TLS)	CONCEPT DESCRIPTION SHEET (CDS)	SCHEMATIC BLOCK DIAGRAM (SBD)	TRADE STUDY REPORT (TSR)	DESIGN SHEET (DS)	FACILITY INTERFACE SHEET (FIS)		TYPE A	TYPE B	TYPE C	OTHER
CONCEPT EXPLORATION																
• REVIEW BASIC SYSTEM CONSTRAINTS TO ASSURE ADEQUATE INPUT TO SE PROCESS												DODD 5000.1 FM 770-78 DODI 5000.2				
• REVIEW AND PREPARE INPUTS TO FUNCTIONAL ANALYSIS TO ASSURE THAT DESIGN CONSTRAINTS, DESIGN CRITERIA, TIME CONSTRAINTS, PERFORMANCE CRITERIA, ETC., REFLECT SPECIALTY NEEDS AND OBJECTIVES	X	X			X	X	X	X			X	FM 770-78 MIL STD 499A				
• PARTICIPATE IN TRADE STUDIES TO SUPPORT SELECTION OF ALTERNATE CONCEPTS									X			FM 770-78 MIL STD 499A				
• PROVIDE NARRATIVE SUMMARIES OF TECHNICAL GOALS WITH SUPPORTING PLANS												ALL SPECIALTIES DODD 5000.40				
DEMONSTRATION/VALIDATION																
• EXPAND INITIAL REQS DEFINED FOR DISCIPLINE AS PART OF SYSTEM FUNCTIONAL ANALYSIS	X				X	X	X	X	X			FM 770-78 MIL STD 499A				
• DEVELOP COORDINATED INPUTS FOR SYSTEM ENGINEERING MANAGEMENT PLAN SHOWING CLEAR PROCESS AND DATA RELATIONSHIPS	X	X	X	X	X	X	X	X	X	X	X	MIL STD 499A ALL SPECIALTIES	X	X	X	X
• PREPARE DETAILED SPECIALTY INPUTS INTO THE SYSTEM SPECIFICATION (TYPE A)												MIL STD 490A MIL STD 499A	X			

Figure 4-5 (2 of 4)
Principal System Integration Tasks

PHASE PRINCIPAL SYSTEM INTEGRATION TASKS	PRIMARY SE DOCUMENTATION INTERFACE											PRINCIPAL MIL SPEC/STD	PRIMARY SPECIFICATION INTERFACE			
	FUNCTIONAL FLOW BLOCK DIAGRAM (FFBD)	END ITEM MAINTENANCE SHEET (EIMS) LOGISTIC SUPPORT ANALYSIS	TEST REQUIREMENTS SHEET (TRS)	PRODUCTION SHEET (PS)	REQUIREMENTS ALLOCATION SHEET (RAS)	TIME LINE SHEET (TLS)	CONCEPT DESCRIPTION SHEET (CDS)	SCHEMATIC BLOCK DIAGRAM (SBD)	TRADE STUDY REPORT (TSR)	DESIGN SHEET (DS)	FACILITY INTERFACE SHEET (FIS)		TYPE A	TYPE B	TYPE C	OTHER
DEMONSTRATION/VALIDATION																
• SUPPORT SYSTEM REQUIREMENTS REVIEW (SRR) BY PROVIDING SPECIALTY INPUTS IN GENERAL TO REQS OF MIL STD 1521B	X				X		X	X				MIL STD 1521B MIL STD 490A	X			
• PARTICIPATE IN ANALYSIS OF LOGISTIC SUPPORT, TESTING, PRODUCTION AND DEPLOYMENT FUNCTIONS TO PROVIDE SPECIALTY INPUT	X				X		X	X				FM 770-78 MIL STD 490A				
• PARTICIPATE IN TRADE STUDIES FOR LOGISTIC SUPPORT, TESTING, PRODUCTION AND DEPLOYMENT, PROVIDE SPECIALTY CRITERIA					X				X			FM 770-78 MILSTD 490A	X			
• PARTICIPATE IN DEVELOPING INITIAL DESCRIPTIONS OF LOGISTIC SUPPORT, TESTING, AND DEPLOYMENT ELEMENTS		X		X			X		X			DODD 5000.39 FM 770-78 MIL STD 490A	X			
• SUPPORT SYSTEM DESIGN REVIEW (SDR) BY DEVELOPING SPECIALTY INPUT TO REQS OF MIL STD 1521B	X	X		X	X	X	X					MIL STD 1521B FM 770-78 MIL STD 490A	X			
• PREPARE INPUTS TO PROPOSED DEVELOPMENT SPECIFICATIONS (TYPE B)					X			X		X		MIL STD 490A FM 770-78 MIL STD 490A ALL SPECIALTY SPECS		X		
• UPDATE INPUTS TO SYSTEM SPECIFICATION												MIL STD 490A MIL STD 490A	X			
• SOFTWARE REQUIREMENT DEFINITION IN SRS AND IRS (TYPE B SPECS)	X				X			X		X		DOD STD 2167		X		

Figure 4-5 (3 of 4)
Principal System Integration Tasks

PHASE / PRINCIPAL SYSTEM INTEGRATION TASKS	PRIMARY SE DOCUMENTATION INTERFACE											PRINCIPAL MIL SPEC/STD	PRIMARY SPECIFICATION INTERFACE			
	FUNCTIONAL FLOW BLOCK DIAGRAM (FFBD)	END ITEM MAINTENANCE SHEET (EIMS) LOGISTIC SUPPORT ANALYSIS	TEST REQUIREMENTS SHEET (TRS)	PRODUCTION SHEET (PS)	REQUIREMENTS ALLOCATION SHEET (RAS)	TIME LINE SHEET (TLS)	CONCEPT DESCRIPTION SHEET (CDS)	SCHEMATIC BLOCK DIAGRAM (SBD)	TRADE STUDY REPORT (TSR)	DESIGN SHEET (DS)	FACILITY INTERFACE SHEET (FIS)		TYPE A	TYPE B	TYPE C	OTHER
DEMONSTRATION/VALIDATION																
• UPDATE INPUTS TO LOGISTIC SUPPORT, TEST, PRODUCTION AND DEPLOYMENT PLANNING												ALL SPECIALTIES PLANNING	X	X		
• PROVIDE TECHNICAL SPECIALTY INPUTS TO ALLOCATED BASELINE												MIL STD 483A	X	X		
• PROVIDE SPECIALTY INPUTS TO PEP AND DT II TEST PLAN	X		X	X	X	X	X	X	X		X					
FULL SCALE DEVELOPMENT																
• PROVIDE SPECIALTY INPUT INTO PRELIMINARY DESIGN FOR OPERATIONAL ELEMENTS	X				X					X		FM 770-78 MILSTD 499A		X		
• TOP-LEVEL DESIGN FOR COMPUTER SOFTWARE	X				X	X	X	X				DOD STD 2167				
• SOFTWARE TEST PLANNING	X		X		X			X				DOD STD 2167				
• PROVIDE SPECIALTY INPUT TO PRELIMINARY DESIGN REVIEW (PDR) FOR OPERATIONAL ELEMENTS					X				X	X		FM 770-78 MIL STD 499A		X		
• PROVIDE SPECIALTY INPUTS INTO PRELIMINARY DESIGN FOR SUPPORT, TEST, PRODUCTION AND DEPLOYMENT FUNCTIONS		X			X				X	X		FM 770-78 MIL STD 499A ALL SPECIALTY SPECS		X		
• PROVIDE SPECIALTY INPUTS INTO PRELIMINARY DESIGN REVIEW (PDR) FOR SUPPORT, TEST, PRODUCTION AND DEPLOYMENT ELEMENTS		X	X	X	X				X	X		MIL STD 1521B		X		
• PROVIDE SPECIALTY INPUTS INTO DETAILED DESIGN								X	X	X		FM 770-78 MIL STD 499A		X	X	

Figure 4-5 (4 of 4)
Principal System Integration Tasks

PHASE PRINCIPAL SYSTEM INTEGRATION TASKS	PRIMARY SE DOCUMENTATION INTERFACE											PRINCIPAL MIL SPEC/STD	PRIMARY SPECIFICATION INTERFACE			
	FUNCTIONAL FLOW BLOCK DIAGRAM (FFBD)	END ITEM MAINTENANCE SHEET (EIMS) LOGISTIC SUPPORT ANALYSIS	TEST REQUIREMENTS SHEET (TRS)	PRODUCTION SHEET (PS)	REQUIREMENTS ALLOCATION SHEET (RAS)	TIME LINE SHEET (TLS)	CONCEPT DESCRIPTION SHEET (CDS)	SCHEMATIC BLOCK DIAGRAM (SBD)	TRADE STUDY REPORT (TSR)	DESIGN SHEET (DS)	FACILITY INTERFACE SHEET (FIS)		TYPE A	TYPE B	TYPE C	OTHER
FULL SCALE DEVELOPMENT																
• PROVIDE SPECIALTY INPUTS INTO TYPE C SPECIFICATIONS									X	X	X	MIL STD 490A			X	
• PROVIDE SPECIALTY INPUTS INTO CRITICAL DESIGN REVIEW(S)					X					X	X	MIL STD 1521B		X	X	
• PROVIDE SPECIALTY INPUTS INTO TEST REQUIREMENTS REVIEW (TRR)			X									DOD STD 2167				
• PROVIDE SPECIALTY INPUT INTO FUNCTIONAL CONFIGURATION AUDIT													X	X	X	
• PROVIDE SPECIALTY INPUTS INTO FORMAL QUALIFICATION REVIEW													X	X	X	X
• PROVIDE INPUTS AND UPDATES INTO PRODUCTION PLANNING FROM SPECIALTY VIEWPOINT													X	X	X	X

CHAPTER 5

THE SYSTEMS ENGINEERING PROCESS

5.1 INTRODUCTION

This chapter summarizes the activities which occur during the systems engineering process and describes the basic steps which comprise the process: functional analysis (function identification, and requirements identification and allocation), synthesis, evaluation and decision, and description of the system elements. The elements which define a system are equipment (hardware), software, facilities, personnel, and procedural data.

The systems engineering process is an iterative process applied throughout the acquisition life cycle. The process itself leads to a well defined, completely documented, and optimally balanced system. It does not produce the actual system itself, but rather, it produces the complete set of documentation, tailored to the needs of a specific program, which fully describes the system to be developed and produced. Each program's systems engineering process, developed through tailoring and/or adding supplemental requirements, must meet certain general criteria. Although not complete, the following guidelines should be considered in one's approach to the basic process [1]:

a. System and subsystem (configuration item) requirements shall be consistent, correlatable, and traceable both within data produced as basic documentation (e.g., Functional Flow Block Diagram (FFBD), Requirements Allocation Sheet (RAS), and Time Line Sheet (TLS)) and as related documentation (e.g., work breakdown structure (WBS) and Logistic Support Analysis Record (LSAR)).

b. The concept of minimum documentation shall be evident.

c. Acquisition and ownership cost shall be an integral part of the evaluation and decision process.

d. Baselines which meet the general guidance of MIL-STD-490A [2] shall be established progressively as an integral part of the systems engineering process.

e. The systems engineering process shall result in a design that is complete, at a given level of detail, from a total system element viewpoint.

f. The process shall provide for the timely and appropriate integration of mainstream engineering with engineering specialties such as reliability, maintainability, human factors engineering, safety, integrated logistic support (ILS), environmental assessments, and producibility to ensure their influence on system design.

g. The process shall provide for

continuing prediction and demonstration of the anticipated or actual achievement of the primary technical objectives of the system. Problems and risk areas shall be identified in a timely manner.

h. Formal technical reviews and audits shall be an integral part of the systems engineering process. The requirements for these reviews and audits are given in MIL-STD-1521B [3].

i. The systems engineering process shall be responsive to change. The impact of changes to system and/or program requirements must be traceable to the lowest level of related documentation in a timely manner.

j. Significant engineering decisions shall be traceable to the systems engineering activities and associated documentation upon which they were based.

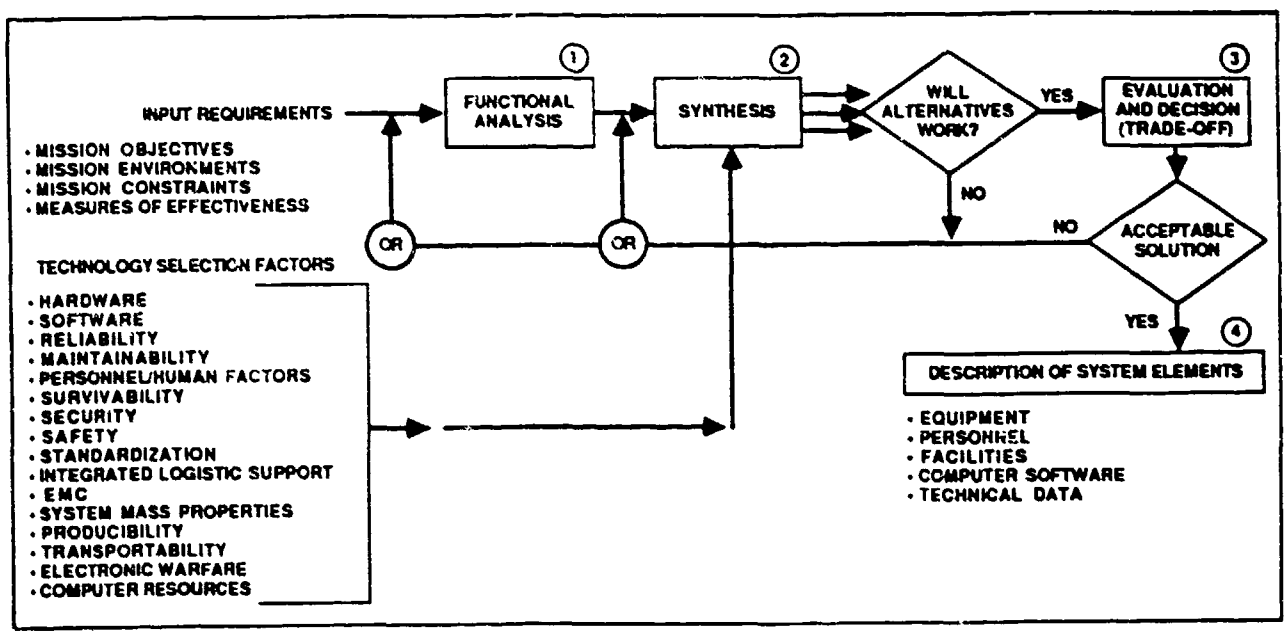
5.2 THE BASIC SYSTEMS ENGINEERING PROCESS

Figure 5-1 presents an overview of the four basic steps of the systems engineering process.

5.2.1 Functional Analysis

Every engineering effort must begin with a statement of a perceived need. At the beginning of a DOD acquisition effort, this statement will be in the form of a system requirement document, usually developed through a Mission Area Analysis of anticipated threats. Once the purpose of the system is known, the functional analysis activity identifies what essential functions the system must perform. In order to accomplish this, functional analysis is composed of two primary process segments: 1) functional identification and 2) requirements identification and allocation (functional

Figure 5-1
The Systems Engineering Process



performance requirements analysis). It answers the **"what"** and **"why"** questions relative to system design. Further detail is provided in Chapter 6 of this guide.

The basic analytical tool for functional identification is the Functional Flow Block Diagram (FFBD), showing logical sequences and relationships of operational and support functions at the system level. Specific functions will vary from system to system and will be traceable to mission requirements and objectives. Maintenance flow diagrams which depict general maintenance and support concepts will lead to analysis of requirements on an end item/equipment basis. At this level, since functions are more standardized, functional identification is often accomplished using the End Item Maintenance Sheet (EIMS) or Logistic Support Analysis Record (LSAR). Similarly, detailed test requirements are identified using the Test Requirements Sheet (TRS), and productivity requirements are identified using the Production Sheet (PS).

It should be kept in mind that the systems engineering process is always iterative. Each acquisition phase will involve functional analysis to progressively more detail. For example, during the Concept Exploration/ Definition (C/E) phase, analysis of support functions will concentrate on Maintenance FFBDs, which will support the establishment of gross maintenance concepts. During Full Scale Development (FSD), emphasis will shift to detailed analysis of the maintenance requirements of specific equipment using the EIMS or LSAR.

The Requirements Allocation Sheet (RAS) is used as the primary analytical tool for requirements identification and allocation, or functional performance requirements analysis as it often is referred to, in conjunction with FFBDs and special purpose documents such as EIMSs, TRSs, and PSs. The RAS serves three purposes in documenting the systems engineering process: 1) initially, it is used to record the performance requirements established for each function; 2) during synthesis, it is used to show the allocation of the functional performance requirements to individual system elements or a combination of elements; and 3) following evaluation and decision, the RAS provides the functionally oriented data required in the description of the system elements.

The Time Line Sheet (TLS) is used to perform and record the analysis of time-critical functions and functional sequences. In performing time requirements analysis for complex functional sequences, additional tools, such as mathematical models or computer simulations, may be needed. Time requirements analysis is performed in any or all of the functional cycles of the process to determine whether time is a critical factor. The TLS complements the FFBD in its ability to show a lower level of detail, as well as to illustrate the impact of concurrent functions within a given sequence. TLSs are used to support the development of design requirements for the operation, test, and maintenance functions. They identify time-critical functions and depict the concurrency, overlap, and sequential relationship of functions and related tasks. Time-critical functions are those that affect reaction time, down time, or availability.

5.2.2 Synthesis

Synthesis supplies the **"how"** answers to the "what" outputs of functional analysis. Further detail on synthesis techniques is presented in Chapter 7 of this guide.

Two documentation tools accomplish and record the synthesis of design approaches or alternative approaches. The Concept Description Sheet (CDS) is used to collect the performance requirements and constraints generated by functional analysis, that apply to an individual subsystem or element. The CDS also describes at the gross level a design approach for meeting the requirements. The Schematic Block Diagram (SBD) is used to develop and portray the conceptual schematic arrangement of system elements to meet system and/or subsystem requirements. The CDS and SBD are both applicable to all acquisition phases and provide the basis for development of the descriptions of system elements.

5.2.3 Evaluation and Decision

Since program risk and cost are dependent on practical trade-offs between stated operating requirements and engineering design, continual evaluations and decisions must be made not only at the beginning of the program but throughout the design and development activity. Several approaches to the evaluation and decision process is presented in Chapter 8 of this guide.

The Trade Study Report (TSR) is used to summarize and correlate characteristics of alternative solutions to the requirements and constraints which establish the selection criteria for a specific trade study area. The report also documents the rationale used in the decision process and should present risk assessment and risk avoidance considerations. Other tools, such as analytical or mathematical models or computer simulations, may be needed and used in accomplishing the evaluation and decision process.

5.2.4 Description of System Elements

All systems can be defined by a set of interacting system elements which fall into five categories: 1) equipment (hardware), 2) software, 3) facilities, 4) personnel, and 5) procedural data. Two documentation forms are used to describe these system elements: 1) the Design Sheet (DS) and 2) the Facility Interface Sheet (FIS). The DS is used to establish and describe the performance, design, and test requirements for equipment end items, critical components, and computer software programs. The FIS is used to identify the environmental requirements and interface design requirements imposed upon facilities by the functional and design characteristics of equipment end items. The DS and FIS provide the basis for the formal identification required for configuration management.

5.3 DOCUMENTATION

The systems engineering process produces the basic and special purpose documentation which controls the evolutionary development of the system. Figure 5-2 correlates the particular documentation associated with each step of the systems engineering process.

The systems engineering process itself

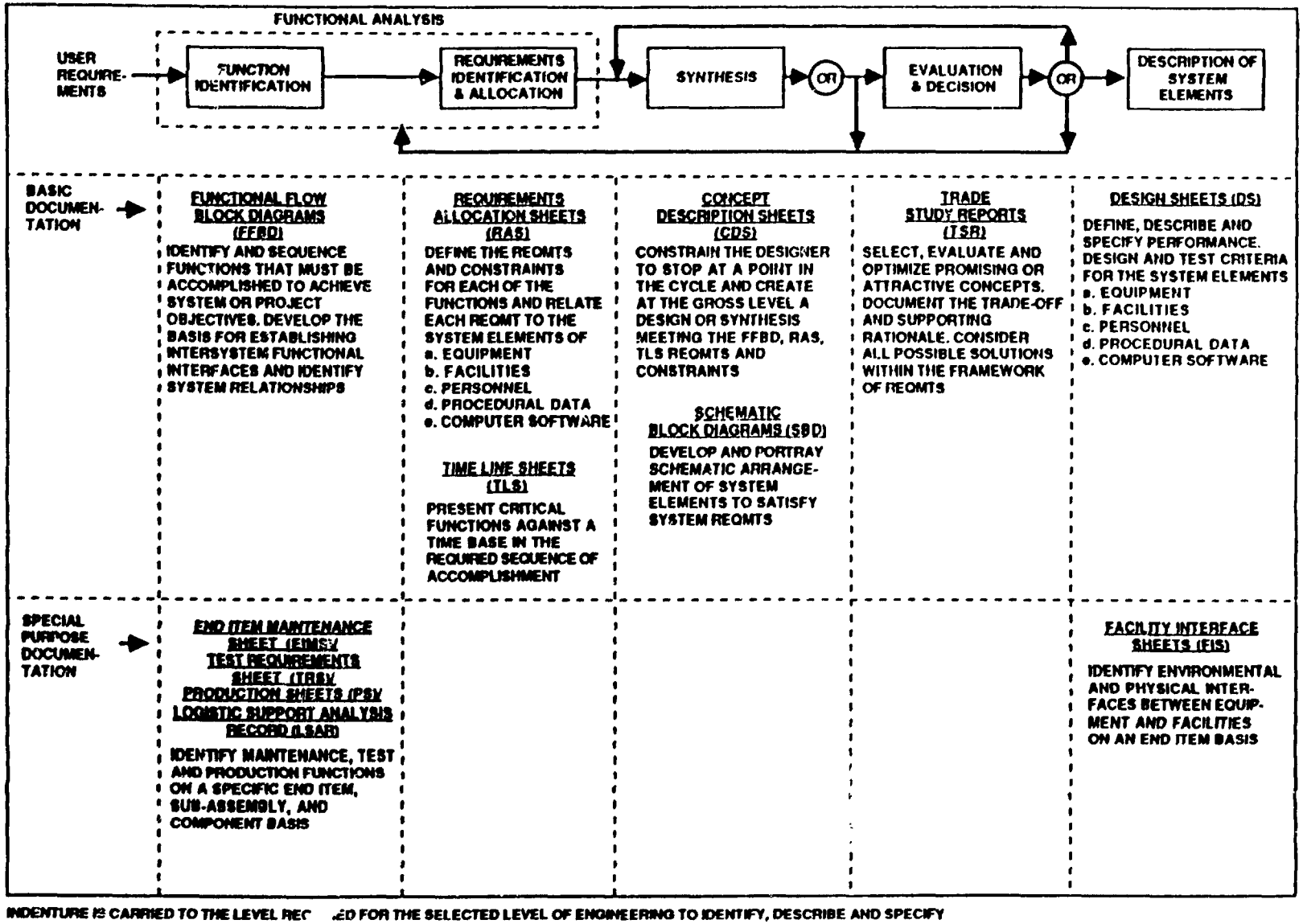


Figure 5-2
Basic and Special Purpose Documentation for Systems Engineering

doesn't actually produce the system, but produces the documentation necessary to define, design, develop, and test the system. As such, a variety of engineering and planning documentation is required throughout the acquisition cycle and systems engineering is the vehicle used to produce that documentation.

Numerous plans are prepared to define which technical activities will be conducted. They address the integration of engineering specialties requirements, "design-for" requirements, and organizational resource requirements, and discuss how progress toward system level goals will be measured. The Systems Engineering Management Plan (SEMP) is the key planning document which reflects these requirements. Contractor compliance with these plans is monitored by government organizations to ensure that standard policies and procedures in the area of systems engineering are employed. Additionally, specifications are prepared as part of the systems engineering process to form the basis for the design and development effort. The top level specification (system or segment) is normally approved and draft lower level specifications (configuration items) are developed reflecting allocated system requirements to lower level components or subsystems, which designers and subcontractors translate into hardware and software production plans.

In order to provide a continuing assessment of the system's capability to meet performance requirements, the systems engineering organization prepares technical review data packages, technical performance measurement (TPM) reports, analysis and simulation reports, and other documentation which normally includes: Interface Control Documents/ Drawings, Trade Study Reports/ Directions, Risk Analysis Management Plan, Survivability/ Hardness Plan, Mission Area Analysis Reports, Functional Analysis Documentation, Reliability Plan, Maintainability Plan, Safety/ Hazard Analysis Plan, Human Engineering Plan, Integrated Logistic Support Plan (ILSP), Electromagnetic Compatibility/ Interference Control (EMC/ EMI) Plan, Test and Evaluation Master Plan (TEMP), Mission Support Plan, and Production Engineering Plan.

5.4 SUMMARY

The systems engineering process is one approach to providing disciplined engineering during all acquisition phases. Although current application of the process has focused on C/E, D/V, and FSD, systems engineering process techniques and principles are equally applicable to the analysis and definition of production requirements. DoD 4257.7-M [4] enables the Program Manager to review and evaluate the products of the systems engineering process from the standpoint of managing risk during the transition from development to production. Chapter 15 of this guide fully describes risk management as it relates to the systems engineering process.

The systems engineering process provides the logic and timing for a disciplined approach, with certain internal assurances of technical integrity such as traceability. Technical integrity ensures that the design requirements for the system elements reflect the functional performance requirements, that all functional performance requirements are

satisfied by the combined system elements, and that such requirements are optimized with respect to system performance requirements and constraints.

5.5 REFERENCES

1. MIL-STD-499A, "Engineering Management"

2. MIL-STD-490A, "Specification Practices"

3. MIL-STD-1521B, "Technical Reviews and Audits for Systems, Equipments, and Computer Software"

4. DOD 4257.7-M, "Transition from Development to Production"

CHAPTER 6

FUNCTIONAL ANALYSIS

6.1 INTRODUCTION

Functional analysis, as the first step in the systems engineering process, defines a baseline of functions and function performance requirements which must be met in order to adequately accomplish the operation, support, test, and production requirements of the system. Functional analysis begins with the identification of top level functions and ends with the allocation of those functions to lower level elements within the system. This effort should be influenced by the synthesis (the second step of the systems engineering process) of system elements in verifying their capability to accomplish the allocated requirements. In other words, functional analysis and synthesis should be performed in concert because the synthesis must be responsive to functional requirements. These functional requirements provide a common basis for the selection and design criteria for system elements and identify areas where trade-offs between input requirements and engineering development require future consideration.

Functional analysis is a method for analyzing performance requirements and dividing them into discrete tasks or activities. It involves the identification and decomposition of the primary system functions into subfunctions at ever increasing levels of detail. It supports mission analysis in defining functional areas, sequences, and interfaces and is also used by engineering specialists to develop requirements for equipment, software, personnel, and operational procedures to complete implementation and deployment of the system. There are two basic activities associated with functional analysis: 1) functional identification and 2) requirements allocation. This chapter describes a number of tools used to accomplish these activities and the means of documenting the effort; it is not meant to provide a detailed guide for undertaking a functional analysis.

6.2 APPROACH

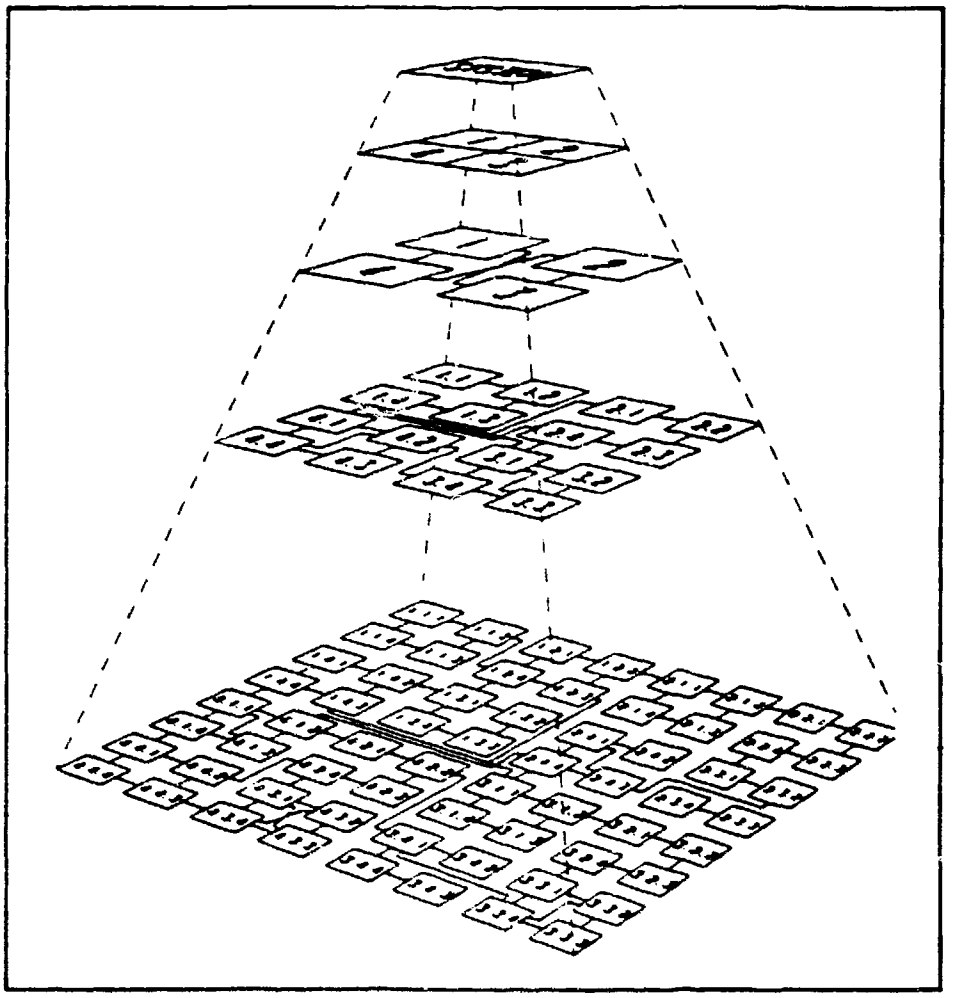
A function is a characteristic action to be accomplished by one of the system elements of equipment (hardware), software, facilities, personnel, procedural data, or any combination thereof. Functional identification and decomposition can be performed with respect to logical groupings, time ordering, data flow, control flow, or some other criterion. The stepwise decomposition of a system can be viewed as a top down approach to problem solving.

This top down approach is illustrated in Figure 6-1, which shows a system being separated into functional areas or segments. Each functional area satisfies an allocated portion of the basic system functions. Collectively, these areas constitute a complete system description at each level. When these segments are separated, as they actually may be in a physical sense, required interface

connections are exposed. As the functions are decomposed to the next lower level (element), the number of functions (requirements) greatly increases, each with its own interfaces. This process continues until the lowest level is reached and where discrete tasks (such as compute range) can be defined and satisfied. Note that traceability is maintained throughout by a decimal numbering system. Although Figure 6-1 shows each function generating an equal number of subfunctions, this is seldom the case for real systems.

One of the most important advantages of top down development is that the most difficult design area can be attacked first throughout its total hierarchy; e.g., in Figure 6-1, doing all of 3 (3.1, 3.2, 3.3; 3.1.1, 3.1.2, 3.1.3, etc.) at the start of the development to reduce risk. It should be noted that top down development is not the same as the top down division of program effort that is employed in developing the work breakdown structure (WBS). However, there appears to be a similarity between the WBS and top down development methodology, since the

Figure 6-1
Top-Down Approach to Functional Decomposition



hardware items and software modules that will perform the discrete and interface tasks identified through functional analysis must be WBS elements.

6.3 FUNCTIONAL IDENTIFICATION

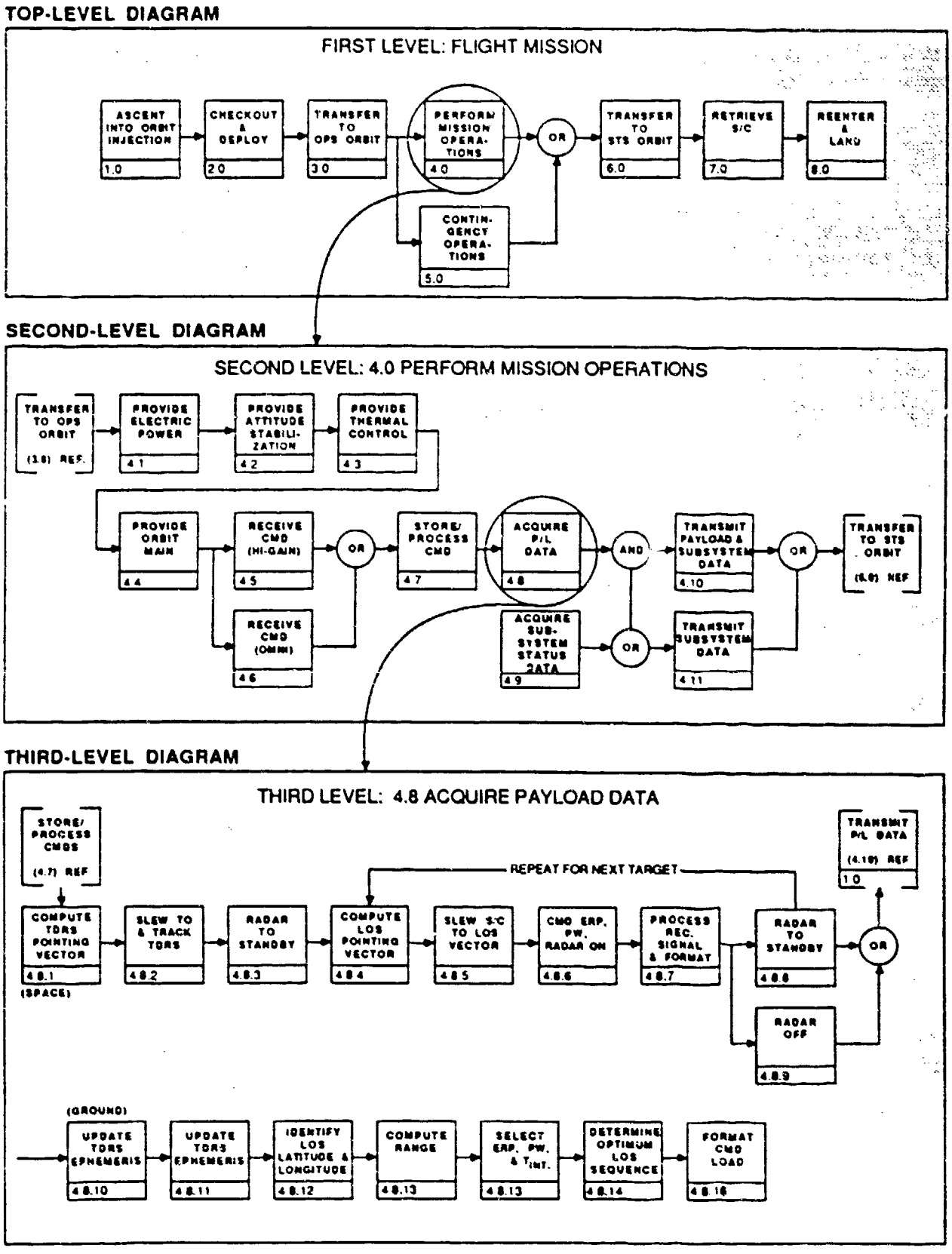
System requirements are analyzed to identify those functions which must be performed to satisfy the objectives of each functional area. Each function is identified and described in terms of inputs, outputs, and interface requirements from top down so that subfunctions are recognized as part of larger functional areas. Functions are arranged in a logical sequence so that any specified operational usage of the system can be traced in an end-to-end path. Although there are many tools available, functional identification is accomplished primarily through the use of 1) functional flow block diagrams (FFBDs) to depict task sequences and relationships, 2) N^2 diagrams to develop data interfaces, and 3) time line analyses to depict the time sequence of time critical functions.

6.3.1 Functional Flow Block Diagrams

The purpose of the FFBD is to indicate the sequential relationship of all functions that must be accomplished by a system. FFBDs depict the time sequence of functional events. That is, each function (represented by a block) occurs following the preceding function. Some functions may be performed in parallel, or alternate paths may be taken. The duration of the function and the time between functions is not shown but may vary from a fraction of a second to many weeks. The FFBDs are function oriented, not equipment oriented. In other words, they identify "what" must happen and do not assume a particular answer to "how" a function will be performed.

FFBDs are developed in a series of levels. FFBDs show the same tasks identified through functional decomposition (such as those portrayed in Figure 6-1) and display them in their logical, sequential relationship. For example, the entire flight mission of a spacecraft can be defined in a top level FFBD, as shown in Figure 6-2. Note that the numbers in Figure 6-1 correspond to the element numbers in Figure 6-2. Each block in the first level diagram can then be expanded to a series of functions, as shown in the second level diagram for "perform mission operations." Note that the diagram shows both input (transfer to operational orbit) and output (transfer to space transportation system orbit), thus initiating the interface identification and control process. Each block in the second level diagram can be progressively developed into a series of functions, as shown in the third level diagram on Figure 6-2. These diagrams are used both to develop requirements and to identify profitable trade studies. For example, does the spacecraft antenna acquire the tracking and data relay satellite (TDRS) only when the payload data are to be transmitted, or does it track TDRS continually to allow for the reception of emergency commands or transmission of emergency data? The FFBD also incorporates alternate and contingency operations, which improve the probability of mission success. The flow diagram provides an understanding of total operation of the system, serves as a basis for development of operational and contingency procedures, and pinpoints areas where changes in operational

Figure 6-2
Development of Functional Flow Block Diagrams

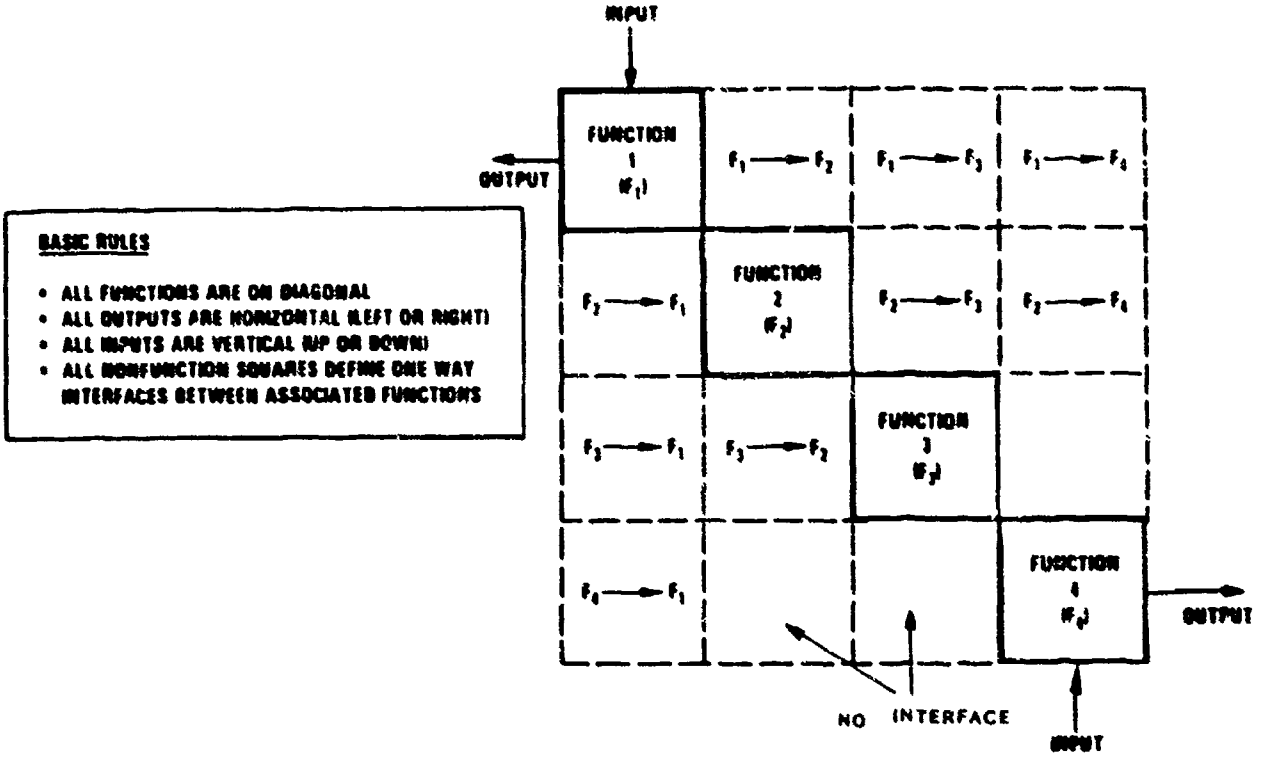


procedures could simplify the overall system operation. In certain cases, alternate FFBDs may be used to represent various means of satisfying a particular function until data are acquired, which permits selection among the alternatives.

6.3.2 N^2 Diagrams

The N^2 diagram has been used extensively to develop data interfaces, primarily in the software areas; however, it can also be used to develop hardware interfaces. The basic N^2 chart is shown in Figure 6-3. The system functions are placed on the diagonal and the remainder of the squares in the N x N matrix represent the interface inputs and outputs. Where a blank appears, there is no interface between the respective functions. Data flows in a clockwise direction between functions; e.g., the symbol $F_1 \rightarrow F_2$ indicates data flowing from function F_1 to function F_2. The data being transmitted can be defined in the appropriate squares. Alternatively, the use of circles and numbers permits a separate listing of the data interfaces as shown in Figure 6-4. The clockwise flow of data between functions that have a feedback loop can be illustrated by a larger circle called a control

Figure 6-3
N2 Chart Definition



loop. The identification of a critical function is also shown in Figure 6-4 where function F_4 has a number of inputs and outputs to all other functions in the upper module. A simple flow of interface data exists between the upper and lower modules at functions F_7 and F_8. The lower module has complex interaction between its functions. The N^2 chart can be taken down into sucessively lower levels to the hardware and software component functional levels. In addition to defining the data that must be supplied across the interface, The N^2 chart can pinpoint areas where conflicts could arise.

6.3.3 Time Line Analysis

Time line analysis adds consideration of functional durations and is used to support the development of design requirements for operation, test, and maintenance functions. The time line sheet (TLS) is used to perform and record the analysis of time critical functions and functional sequences. Additional tools such as mathematical models and computer simulations may be necessary. Time line analysis is performed on those areas where time is critical to the mission success, safety, utilization of resources,

Figure 6-4
N2 Chart Key Features
(From "The N2 Chart", R. Lano, Copyright 1977 TRW Inc.)

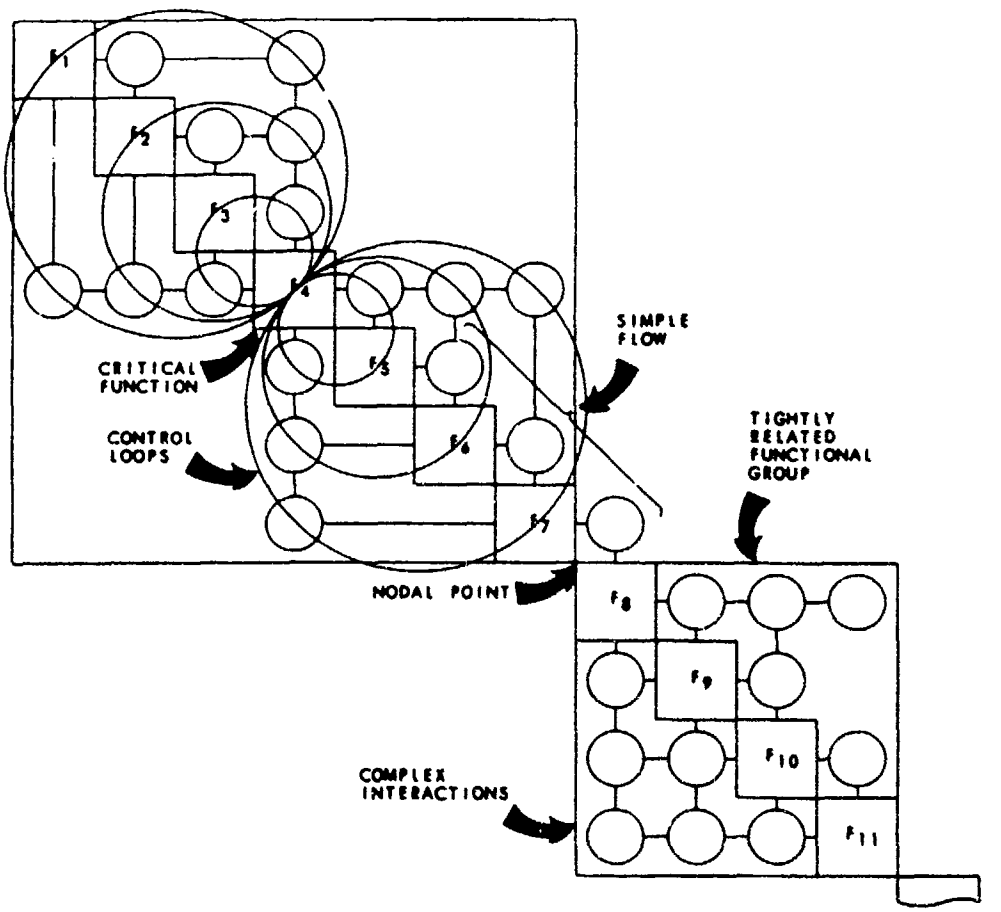
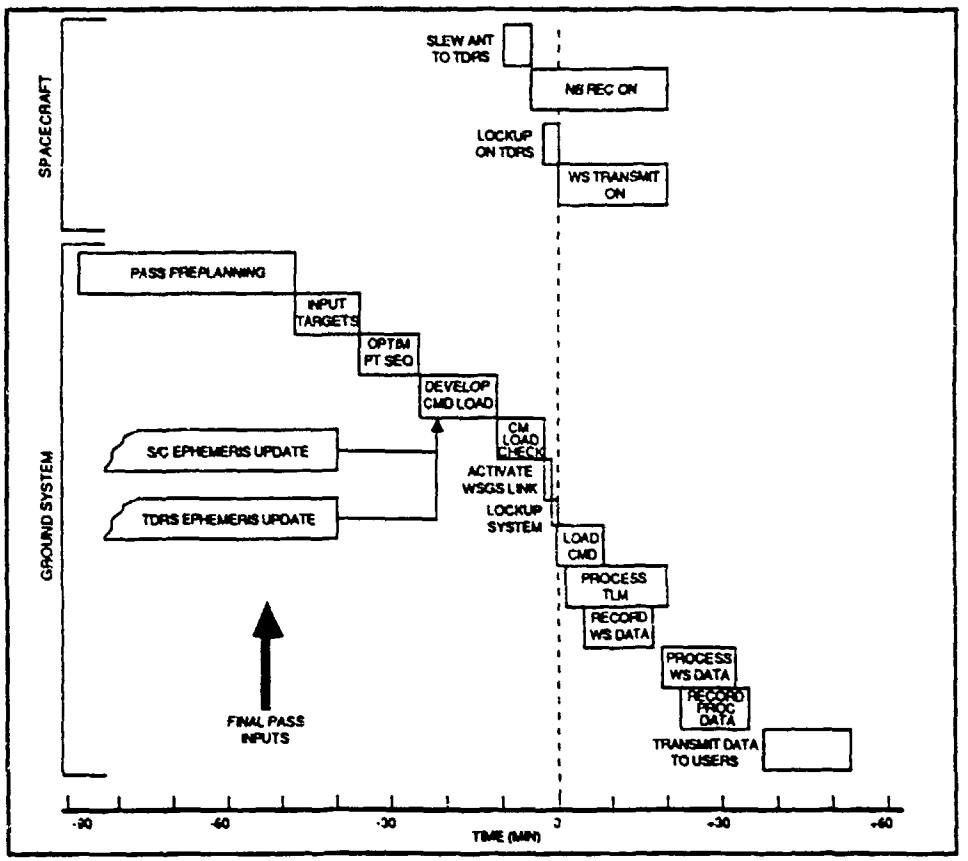


Figure 6-5
Flight Mission Time Lines



minimization of down time, and/or increasing availability. Not all functional sequences require time line analysis, only those in which time is a critical factor. The following areas are often categorized as time critical: 1) functions affecting system reaction time, 2) mission turn around time, 3) time countdown activities, and 4) functions requiring time line analysis to determine optimum equipment and/or personnel utilization. An example of a high level TLS for a space program is shown in Figure 6-5.

For time critical function sequences, the time requirements are specified with associated tolerances. Time line analyses play an important role in the trade-off process between man and machine. The decisions between automatic and manual methods will be made and will determine what times are allocated to what subfunctions. In addition to defining subsystem/ component time requirements, time line analysis can be used to develop trade studies in areas other than time considerations; e.g., should the spacecraft location be determined by the ground network or by onboard computation using navigation satellite inputs? Figure 6-6 is an example of a maintenance TLS which illustrates that availability of an item (distiller) is dependent upon the completion of numerous maintenance tasks accomplished

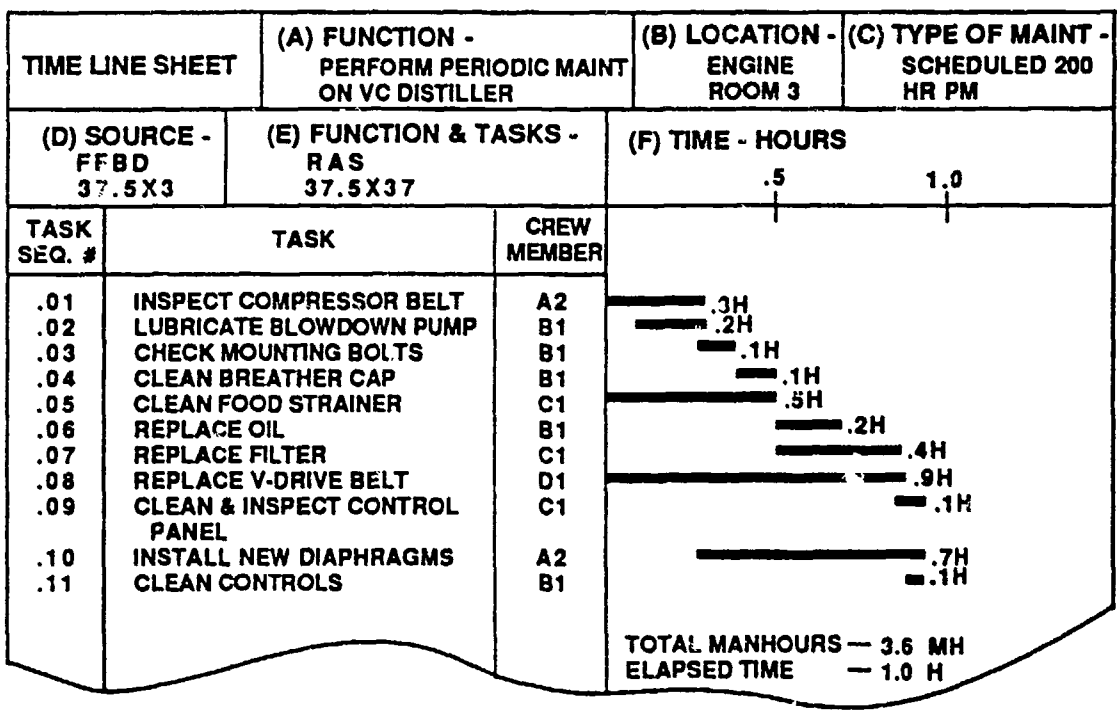
concurrently. Furthermore, it illustrates the traceabilty to higher level requirements by referencing the appropriate FFBD and requirement allocation sheet (RAS).

6.4 REQUIREMENTS ALLOCATION

Requirements allocation is the further decomposition of system level requirements until a level is reached at which a specific hardware item or software routine can fulfill the needed functional/ performance requirements. It is the logical extension of the initial functional identification and an integral part of any functional analysis effort. Some straightforward allocation of functional requirements can be made, but the procedure may involve the use of supporting analyses and simulations to allocate system level requirements. An example of the need for additional analysis is the allocation of availability goals to configuration items. These goals can only be expressed as maintainability and reliability requirements. Allocations and trade studies will be made by these parameters (maintainability and reliability), but only in conjunction with analytical and/or computer simulation to ascertain the impact of a given set of allocations on system availability.

A critical aspect of the documented systems engineering process is the need to provide traceability. Traceability is the ability to move to progressively higher or lower levels of analysis documentation. It includes tracking the allocation design (and technical program) requirements through the WBS

Figure 6-6
Sample Maintenance Time Line Sheet



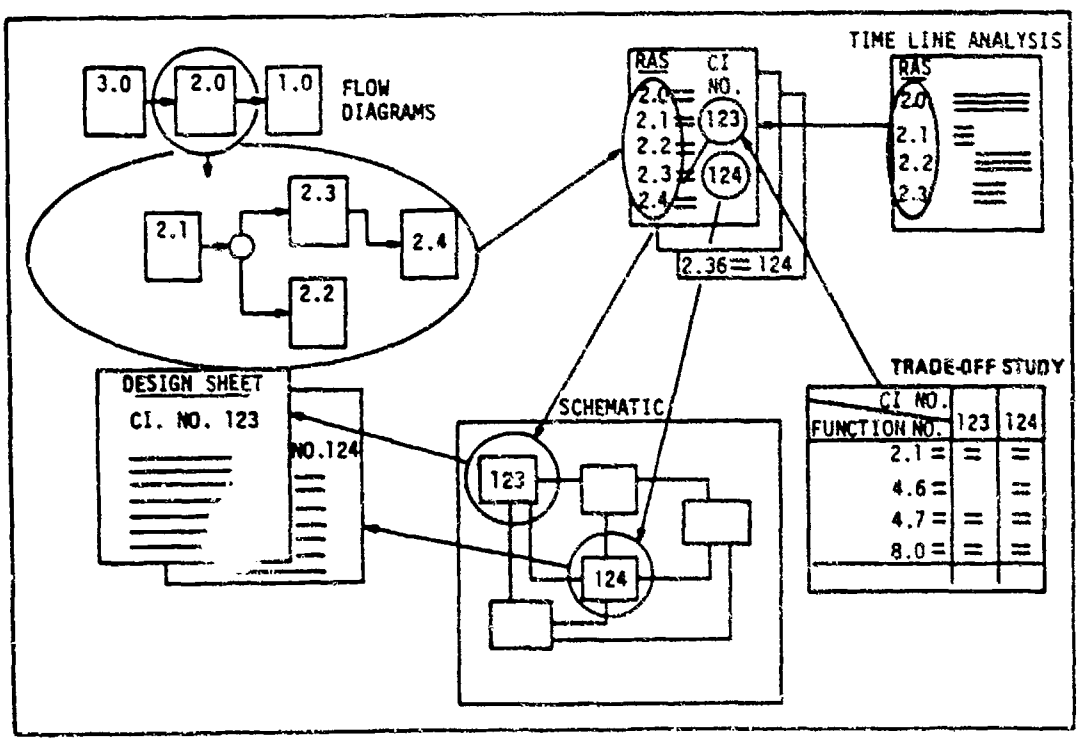
between the system level and the lowest level of assembly. Traceability of systems engineering documentation ensures that the impact of changes to requirements at any level of the systems engineering documentation or program specifications can be reviewed for impact on the total system, and that the rationale can be reviewed without the need to reconstruct analyses. The concept of traceability is graphically illustrated in Figure 6-7.

The systems engineering documentation described in Chapter 5 of this guide provides the audit trail for allocation traceability. Figure 6-7 portrays an example of the mechanics used to provide traceability within the systems engineering documentation.

Prior to synthesis, all requirements and other analytical data are oriented to functions and are identified by the function number to which they pertain. During synthesis, system elements or candidate elements are identified to satisfy the functional performance requirements. After synthesis, all requirements and other design data are oriented to system elements, and are identified by the appropriate configuration item (CI) number (or similar identification for other elements). Any program's tailored or contractor format documentation must have similar capability.

The end result of the requirements allocation process is the development of the system level (Type A) specification and

Figure 6-7
Traceability in Systems Engineering Documentation



development (Type B) specifications that represent the product of the systems engineering process. The importance of a well documented requirements allocation cannot be overemphasized; it forms the foundation of the overall systems engineering effort.

The flowdown of system requirements to lower levels is based upon the mission area analysis (MAA) and system level FFBDs. The initial source of the requirements is the Justification for Major System New Start (JMSNS). The JMSNS defines the mission need, identifies boundary conditions, and outlines the initial acquisition strategy. The JMSNS is produced through government mission area analysis studies which precede the Concept Exploration/ Definition (C/E) phase. These requirements are often summarized for the contractors in a system requirements document. During the C/E and Concept Demonstration/ Validation (D/V) phases, requirements from this document are further analyzed by each contractor through the systems engineering process and incorporated into the system specification and flowed down to the lower level development specifications.

Systems engineering documentation for requirements allocation provides a vehicle for system specialists to document initial allocation of technical parameters such as weight, reliability, system error, and maintainability prior to the availability of the development specification for configuration items. The systems engineering documentation integrates technical budgets, provides requirements traceability, and ensures a consistent consideration of all constraining parameters at all levels of evaluation and decision.

The systems engineering process should avoid indiscriminate decomposition and non-time/ resource bounded analysis. Specific goals related to the depth and scope of identification and allocation of requirements should be clearly stated in the Systems Engineering Management Plan (SEMP). Detailed guidance for tailoring the systems engineering process and documentation is provided in MIL-STD-499A [1]. Often these tailoring goals can be best stated in the SEMP as a requirement for the support that systems engineering analysis and documentation will be expected to provide for the formal technical review process.

The requirements analysis is usually considered complete when a further decomposition of functions or tasks does not result in additional requirements for equipment, facilities, software, or personnel. Decomposition of functions should only be carried out to the point where further analysis will not yield additional performance requirements which must bear on synthesized and/or selected system elements. Once configuration items have been identified for candidate systems, requirements are carried to further levels of detail in the development specifications), engineering drawings, and related engineering documentation. The transition from Type B to product (Type C) specifications would normally begin following Preliminary Design Review (PDR) and should be essentially complete by Critical Design Review (CDR).

6.4.1 Requirements Allocation Sheet

The primary documentation used for

requirements identification and allocation is the requirements allocation sheet (RAS). The RAS, illustrated in Figure 6-8, is initially used to document the performance requirements for each function depicted in the FFBD. During functional analysis, as lower level functions are identified, the RAS rather than the FFBD is generally used to document functions which are not time critical, to avoid many levels of FFBD graphic expansion. An RAS will usually be developed for each function block; however, there are cases where a group of blocks having closely related functions may be analyzed by a combined RAS. Performance requirements are stated in terms of 1) the purpose of the function; 2) performance parameters; 3) design constraints; and 4) requirements for reliability, human performance, safety, operability, maintainability, and transportability. Following synthesis of candidate configuration items, the RAS is used to allocate functional performance requirements to individual system elements (hardware, computer software, personnel, technical manuals, or facilities) or a combination of elements. Although the RAS is a useful tool throughout the acquisition cycle, its role gradually diminishes following completion of preliminary design.

The physical format of a particular application of the RAS is very flexible. It may be expanded either vertically or horizontally. In most cases it will have no physical form, but will be a computer file. Both qualitative and quantitative performance requirements resulting from analysis of the function are identified on the RAS. These requirements are generally identified and grouped by engineering specialty. Requirements are expanded in sufficient detail to provide criteria for synthesizing and evaluating alternative concepts for satisfying each functional requirement in terms of

Figure 6-8
Requirements Allocation Sheet

REQUIREMENTS ALLOCATION SHEET	FUNCTIONAL DIAGRAM TITLE AND NO OR NOMENCLATURE AND NO. OF CI		EQUIPMENT IDENTIFICATION		PERSONNEL AND TRAINING EQUIPMENT REQUIREMENTS				PROCEDURAL DATA REQUIREMENTS
	FUNCTIONAL PERFORMANCE AND DESIGN REQUIREMENTS	FACILITY REQUIREMENTS	NOMENCLATURE	CI OR DETAIL SPEC OR INDEX OR MASTER CONTROL NUMBER	TASKS	TIME REQ	PERFORMANCE REQUIREMENTS	TNG & TNG EQUIP REQ	

combinations of system elements. The RAS should provide all design requirements and/or constraints that apply to the system element that may be selected or designed to perform the function. Requirements are developed in equal depth for operational, maintenance, test, and production functions identified in FFBDs within any tailoring constraints established in the SEMP.

The objectives of the performance and design requirements entries on the RAS, when used to support the system level FFBDs during C/E and D/V, are to establish functional and design requirements that are included in the design sheet (DS) and subsequently incorporated into the requirements section of the system and development specifications. The entries also initiate recognition of intrasystem and intersystem interface and facility requirements, computer software and hardware requirements, and personnel requirements.

Performance and design requirements entries include a description of the function, including the "why" and "what" of the function. That is, the descriptions answer the questions: 1) Why is the function necessary? 2) Why should the function be accomplished at this point in the sequence of activities? 3) What are the detailed engineering and support characteristics of this function?

Performance and design requirements entries on the RAS also include specific design characteristics created by the function; in other words, input, output, performance values, and allowable quantitative tolerances. They also include applicable maintenance constraints such as check out limit, calibration limitations and requirements, and accessibility requirements. Detail supplied on the RAS should be sufficient for direct use as design trade-off criteria which initiate and control the system and system element design. Sufficient technical detail should be given to allow portions of one or more RASs to be extracted and, in conjunction with schematics, assembled in the DS as integrated design requirements.

Personnel task analysis and performance requirements for all tasks are listed separately from the identified functions. These requirements include performance time as well as attributes such as crew coordination, job knowledge, safety, skill, and life support. Requirements for training and training equipment are also identified. Where multiple personnel are involved, TLSs may also be required. At lower levels of analysis, the RAS will encompass a task analysis which provides a system oriented basis for the development of technical manual procedures as well as human engineering analysis and other task analysis methodologies. Time constraints either created by or affecting the function are identified. Such constraints might include computation, countdown, or availability times. All technical and engineering specialty requirements which constrain or have significant influence on design are specified on the RAS. These requirements include factors such as power, physical dimension and weight, controlled and natural environment, reliability, maintainability, and human performance capabilities and limitations.

Functional and technical interface requirements are separately specified and quantified on the RAS. Where intersystem

interface is specified, the configuration of that system is specified, together with the technical characteristics of the interface. When any of the above entries are products of trade study reports (TSR), other back up studies, specifications, or other sources, the applicable source is specifically referenced.

Facility requirements imposed by the performance and design requirements are identified on the RAS. Controlled and natural environmental requirements such as temperature and humidity ranges, illumination and noise levels, wind and snow loading, precipitation, penetration and abrasion effect, and atmospheric pressure are also identified. In addition, facilities that must be developed or scheduled on a long lead basis to test the system's capability to withstand specific environmental and utility requirements such as power (e.g., electrical and hydraulic), air conditioning, ventilation, and heating are identified on the RAS. These requirements begin to emerge in the C/E phase and should be substantially complete by CDR.

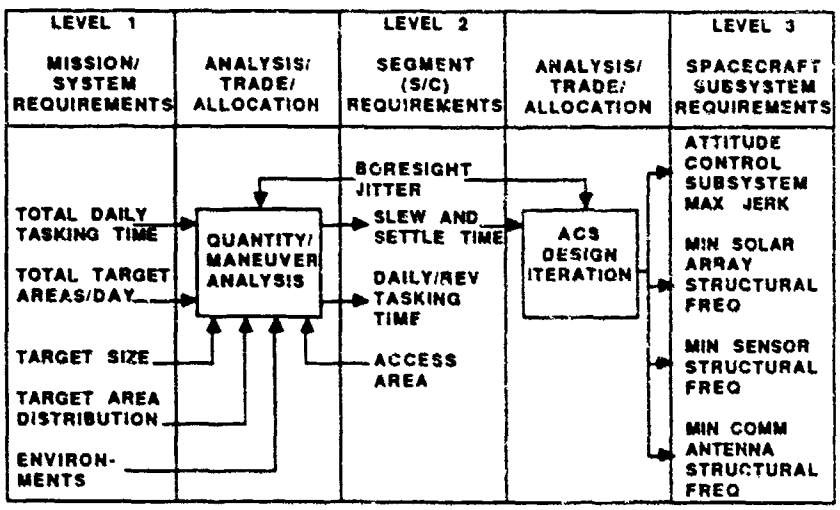
Functions which produce complicated or hazardous requirements involving personnel will generally dictate the need for procedural information. The RAS provides the means for ensuring that the developer has programmed development of the procedural data.

6.4.2 Performing Technical Allocation

Performance requirements can be divided into allocable and non-allocable parameters. An example of the former is weight, which is progressively divided at successively lower levels. An example of the latter is material and process standards, which are applied directly to all elements.

Allocable parameters can be divided into those that are allocated directly and those that are allocated indirectly. A fire control system pointing error is representative of directly allocated requirements in which the total pointing error is apportioned first to the various elements and then to subsystems and their components. Indirectly allocated

Figure 6-9
Example of Technical Requirements Allocation



requirements are those that require an analysis to establish performance measures. An example of this would be the conversion of the mission requirement for aircraft target detection size and range into radiated power, pulse width, and timing stability which could then be used by the designer of the radar system in sizing his hardware. The flowdown and technical allocation process is illustrated in Figure 6-9. The top level performance measures are used to derive lower level subsystem requirements for configuring components. The process is documented in RASs which define each requirement, identify its source, and show the allocation to the next lower level.

It is important to note that as a result of the system analysis and flowdown, top level functional requirements usually become lower level performance requirements. For example:

a. System - Transmit collected data in real time to remote ground site

b. Segment - Provide wideband data link from spacecraft to relay

c. Element - Provide 10 MHz link at 17.0 GHz

d. Subsystem - Provide 10 MHz link at 17.0 GHz with 10 W effective radiated power for 20 minutes maximum per orbital revolution.

In addition, support requirements for power, commands, and telemetry are developed and quantified. The most straight forward application of allocation is the direct apportioning of a value to its contributors. The resulting allocation for a specific area, such as pointing error, is usually referred to as a budget. The technical budget represents an apportionment of a performance parameter to several sources. This may be a top down allocation, such as a pointing error budget, or a bottom up summation, such as an electrical power budget. A discussion of two critical area technical budgets will illustrate the nature of the process: 1) pointing error and 2) electrical power. Characteristics such as pointing error or electrical power distribution would normally become parameters for technical performance measurements (TPM).

6.4.2.1 Pointing Error

Allowable pointing error is a critical issue on all missile and spacecraft programs. Typical errors range from several tenths of a degree to a few arc seconds for astronomical observatory spacecraft. In defining the error budget, it is necessary to first establish those hardware and software characteristics that contribute to the error, otherwise known as error sources. Sample error sources for a communication spacecraft are indicated in Figure 6-10. Individual values for errors would be obtained from specifications for candidate components, experience from similar projects, or extrapolation of experimental data. Where data are totally lacking, values for errors could be obtained through analysis. Typically, a minus two sigma (0.95 probability) value is stated in the specification. This assumes normal distribution with a 95 percent confidence in the error being less than stated. For the above example, the error sources are root-sum squared to arrive at a total, since

Figure 6-10
Sample Error Sources for Spacecraft

SUBSYSTEM	ITEM	ERROR SOURCE
PAYLOAD	ALIGNMENTS	FEED-TO-ANTENNA ANTENNA-TO-MOUNT
	THERMAL DISTORTION STRUCTURAL FLEXURE	
STRUCTURE	ALIGNMENTS	PAYLOAD-TO-GYRO
	STAR SENSOR-TO-GYRO	
	THERMAL DISTORTION	
	DYNAMIC FLEXURE	
ATTITUDE CONTROL	STAR SENSOR	RANDOM ERRORS ABERRATIONS
	GYROS	SCALE FACTOR ESTIMATION SCALE FACTOR STABILITY SCALE FACTOR NONLINEARITY DRIFT AND SCALE FACTOR
	CONTROL DYNAMICS	BIAS
CMD & CONTROL	COMPUTER PROCESSING	STAR DATA BASE STORAGE ROUND-OFF AND TIMING
GROUND SYSTEM	TRACKING EPHEMERIS COMMAND	TARGET LOCATION UNCERTAINTY
	MARGIN	(A QUANTITY RETAINED AT THE SYSTEM LEVEL TO ACCOUNT FOR MANUFACTURING VARIATIONS AND UNCERTAINTIES IN ACCURATELY DEFINING THE VALUE OF ERROR SOURCES, ETC.)

they are random and uncorrelated. The allocated pointing requirements would be placed in subsystem and component specifications as appropriate.

6.4.2.2 Electrical Power

Electrical power is a support requirement determined by summing the individual component loads. It is usually defined by average load, peak load, and a profile of power demands over the total mission sequence. In developing this profile, all electrical items in the design must be identified and a mission operational scenario developed to define equipment operation and duration. Total power requirements in each mode are established and a power profile is developed. The peak and average power requirements are then defined to size the power subsystem. Because some items may be based on only a conceptual design, and because power needs tend to increase, a power control plan is often used that incorporates margins early in the design process to allow for contingencies that may arise. The plan also provides for periodic review of requirements.

6.5 DOCUMENTATION

Documentation of requirements allocation is an essential element of the traceability process. The basic allocation document is

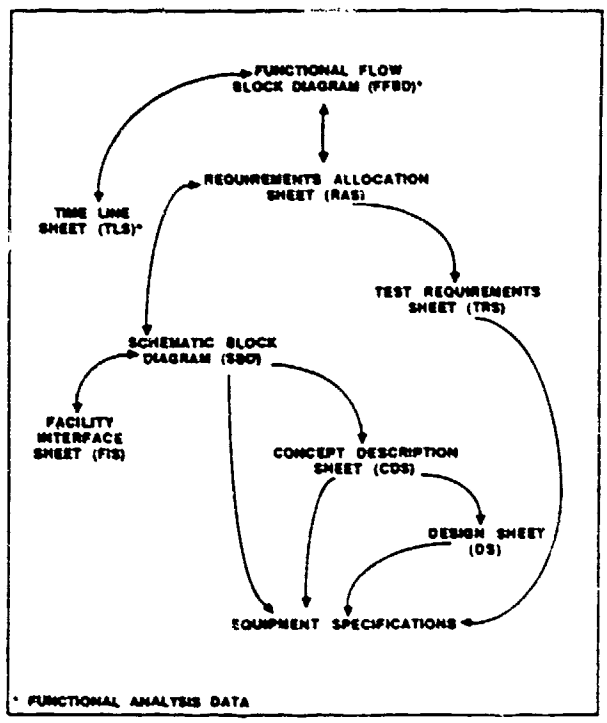
the RAS, shown previously in Figure 6-6. All analyses resulting in allocations should be documented by the RAS and DS. The concept of minimum documentation (tailoring of documentation) should prevail. In most cases a minimum amount of systems engineering documentation is required to be formally submitted to the government.

Technical budgets are also frequently maintained in a performance budget document. This provides a single repository for items that are normally dispersed in a number of specifications and permits a ready assessment of the impact of a change in any value. Where critical budgets are involved, these may be identified as TPM parameters and their status reported. The relation of technical budgeting required by specialty specifications (e.g., reliability and weight control) to systems engineering must be fully described in the SEMP.

6.6 SUMMARY

Functional analysis forms the foundation for all systems engineering. The principal ways in which the functional analysis is documented are FFBDs and RASs. In some cases, TLSs are necessary to document time critical functions. Figure 6-11 illustrates some principal relationships between elements of the systems engineering documentation. In most applications, the "sheets" listed will probably be the computer files with related subsets of data elements. Figure 6-11 also illustrates the relationships among primary hardware documentation. System software data are discussed in greater detail in Chapter 20 of this guide.

Figure 6-11
Principal Relationships of Primary Systems Engineering Documentation



6.7 REFERENCES

1. MIL-STD-490A, "Specification Practices".

2. MIL-STD-499A, "Engineering Management".

3. DI-S-3604/S-126-1, "Functional Flow Diagrams".

4. DI-S-3605/S-127-1, "Requirements Allocation Sheets".

5. DI-S-3605/S-130-1, "Time Line Sheets".

CHAPTER 7

SYSTEM SYNTHESIS

7.1 INTRODUCTION

The task of synthesis is defined in MIL-STD-499A [1]:

"The performance, configuration, and arrangement of a chosen system and its elements and the technique for their test, support, and operation shall be portrayed in a suitable form such as a set of schematic block diagrams, physical and mathematical models, computer simulations, layouts, detailed drawings, and similar engineering graphics. These portrayals shall illustrate intra-\ and inter-system and item interfaces, permit traceability between the elements at various levels of system detail, and provide means for complete and comprehensive change control. This portrayal shall be the basic source of data for developing, updating, and completing (a) the system, configuration item (CI), and critical item specifications; (b) interface control documentation; (c) consolidated facility requirements; (d) content of procedural handbooks, placards, and similar forms of instructional data; (e) task loading of personnel; (f) operational computer programs; (g) specification trees; and (h) dependent elements of work breakdown structures (WBS)".

One of the main objectives of the systems engineering process is to strike a balance among functional performance requirements, system constraints, and system effectiveness criteria in determining the appropriate design concept(s). Synthesis, or conceptual design, is the activity which assures that system influences are given the proper consideration in arriving at a design concept. It is the point in the systems engineering process where engineering creativity and technology are brought to bear in the creation of a system or design concept which best meets the stated system requirements. Synthesis considers the results of various technical and design studies as well as the requirements delineated from the functional analysis effort. It requires the inputs from all of the technology and engineering specialty areas that have a bearing on the system or design concept and should take into account the latest technological advances in the areas of design, producibility, and supportability.

Synthesis is performed initially to postulate possible technical approaches using the results from the functional analysis activity. In supporting each technical approach, one or more system concepts (arrangements of system elements which will satisfy the functional performance requirements) will be identified. Later, during successive iterations of the systems engineering process, one or more design concepts will be synthesized for each system concept. The configuration and arrangement of system elements may be portrayed in any suitable form; however, the two most widely accepted synthesis documentation tools are:

1) the schematic block diagram (SBD) and 2) the concept design sheet (CDS).

Synthesis of solutions, developed during the Concept Exploration/ Definition (C/E) phase, is accomplished only to the level to which the government wishes to constrain the competing Concept Demonstration/ Validation (D/V) phase contractors. During the Full Scale Development (FSD) phase, synthesis develops still greater levels of detail until drawings and specifications are produced which can be used in the fabrication and assembly of hardware, and the coding and assembly of software programs. Portrayal of a synthesized system in terms of its elements (equipment, software, facilities, personnel, and procedural data) will provide a source of data for equipment design documentation, interface control documentation, consolidated facility requirements, handbooks and guide books, task loading of personnel, specification tree, and work breakdown structures (WBS).

In summary, synthesis is the development of "how" answers to the "what" tasks in the functional description of the proposed system.

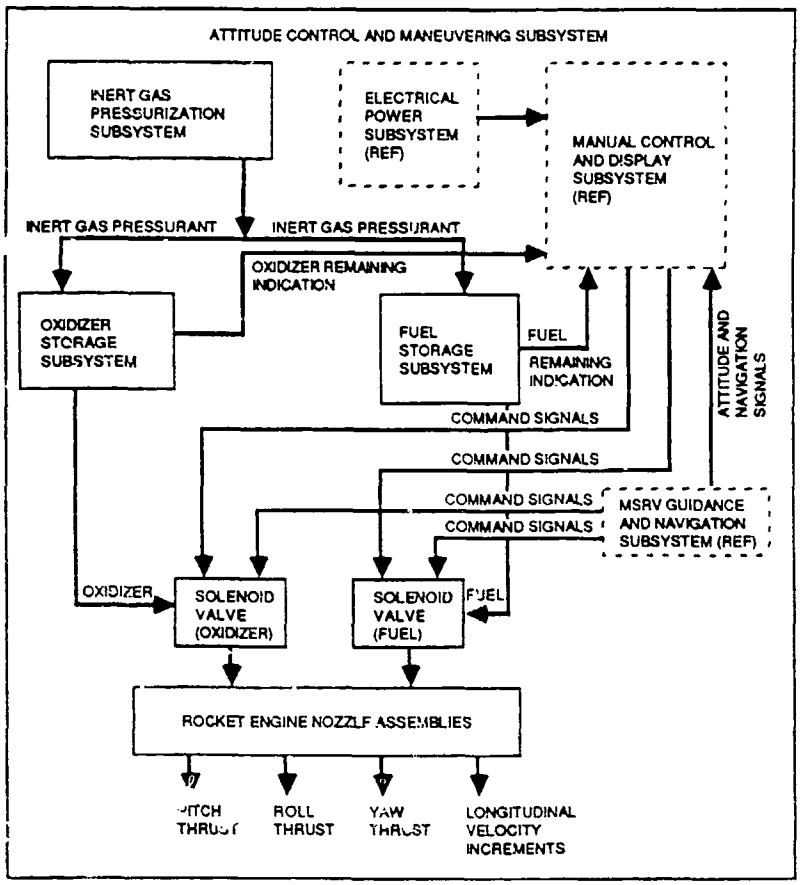
7.2 SYNTHESIS TOOLS

System synthesis originates from the definition of system heirarchy and the specification tree. The government often defines the functional requirements of the system, as well as constraints on the system, such as the use of existing equipment. These are used to define the overall system level functional flow depicted in the functional flow block diagram (FFBD). The CDS is used to collect the performance requirements and constraints as delineated by functional analysis that apply to an individual subsystem or end item, and to describe a design approach for meeting the requirements. When sufficient functional identification and decomposition has occurred, the configuration and arrangement of system elements are portrayed in SBDs. These detailed block diagrams are the basis for system synthesis as shown in Figure 7-1, by serving as the basis for models of the system. These models can either be physical or mathemetical. The development of models requires the systems engineer to organize, evaluate, and examine the validity of his/ (her) thought processes. Their use permits an optimization of hardware and software parameters, allows perfromance predictions to be made, permits operational sequences to be derived, and allows evaluation to the optimun allocation of functional requirements between the system elements.

7.2.1 Schematic Block Diagrams

A schematic block diagram (SBD) is one of the primary tools for the system synthesis by serving as the basis for models of the system. They are developed at successively lower levels as analysis proceeds to define lower level functions within higher level requirements. These requirements are further subdivided and allocated using the Requirements Allocation Sheet (RAS). SBDs provide visability of related system elements, and traceability to the RAS and other systems engineering documentation. Furthermore, SBDs 1) depict a complete response to the functional need which meets the initial input requirments, 2) depict compatibility between the elements of the

Figure 7-1
Schematic Block Diagram



system and interfacing systems/ subsystems, 3) permit traceability between elements and their functional origin, and 4) ensure complete and comprehensive change control.

The SBD shows selected functions and data interfaces within the system. A simplified SBD, Figure 7-1, shows the components which may comprise a subsystem, and the data which may flow between them. An expanded version is usually developed which displays the detailed functions performed within each component and their interrelationships. For complex systems, this may then be developed into a logic diagram for auditing the schematics produced by design engineers. This audit is a critical systems engineering function. The SBD is used to develop Interface Control Documents (ICDs) and provide an overall understanding of system operations. A key goal of the SBD is to define "modular units." Modular units can be characterized as follows **[2]**:

a. Implementing a single, independent

function

b. Performing a single logical task

c. Having a single entry and exit point

d. Being separately testable.

Desirable attributes of the modular units include low coupling, high cohesion, and low connectivity. Coupling between modules is a measure of their interdependence, or the amount of information shared between two modules. Decoupling of modules eases development risks and makes later modifications easier to implement. Cohesion (also called binding) is the similarity of tasks performed within the module. Various levels of cohesion have been defined as follows (highest to lowest) [3]:

a. Functional- all functions contribute directly to performing a single function

b. Sequential- data flow is processed sequentially from input to output

c. Communicational- operates on common data

d. Procedural- follows a logic flow path

e. Temporal- performs differing functions at the same time

f. Logical- performs several similar but unrelated functions.

Connectivity is the reference from internal elements within one module to internal elements within another module. High connectivity is undesirable in that it creates complex interfaces which may impede design, development, and testing.

7.2.2 Physical Modeling

Physical models can be either full size, scale, hardware, or analog representations of the system. Where human interaction is involved, such as manned vehicles or control consoles, the models are frequently built full size, in either soft (foam core or plywood) or hard (metal) construction. Human engineering personnel use them to verify operator capabilities, optimum location of controls, and response times, as well as to establish maintainability characteristics and ensure maximum efficiency of operation. Full scale models are also used by designers to provide a three dimensional representation of complex structures to facilitate design of features such as cable harness routing, box placement, and access opening location.

For missiles and aircraft, scale models are tested in wind tunnels to establish lift and drag characteristics for subsequent use in computer flight simulations. Scale ship and submarine hull models are tested in model basins (towing tanks) to establish hull behavior and expected performance when subjected to a range of operating conditions (such as wave forms or sea states). Scale models also assist designers in visualizing a concept or operation where a full scale model is either impractical or too costly, such as a space station.

Engineering hardware models are often used to provide proof of functional operation or to establish critical performance characteristics. A typical example would be a breadboard or brassboard (for radio

frequency components), which may bear little resemblance to the final operational configuration, but permits demonstration of basic principles. Data gathered provide early verification and permit optimization of the final design.

Analog models are a physical representation of a system in an alternate form. Typically, electrical circuitry is used to represent a mechanical system. A common use is in control system analysis. The analog model is essentially a computer simulation using amplifiers, capacitors, and feedback to solve mathematical equations representing physical system functions. The nature of the circuitry employed permits real time parameter variations which greatly reduce analysis time. Limitations in accuracy and complexity, however, restrict the use of analog models, especially as digital computers have grown in capability. Their current use is primarily in hybrid operation with digital computers representing the control elements in large system simulations.

7.2.3 Mathematical Modeling

A mathematical model is an abstract representation (without regard to physical implementation) of a system. For this reason, it provides a means of developing quantitative performance requirements from which candidate designs can be developed. Static models are those that depict conditions of state, such as the loading of a mechanical structure. If the equilibrium condition is changed by altering the loading conditions, new values for the load paths may be obtained analytically, but the model does not indicate the manner in which the load paths achieved their new state. Should it be desired to optimize the load paths according to the capability of structural members, a numerical solution would be required.

Dynamic models depict conditions that vary with time, such as the action of an autopilot in controlling an aircraft. Simple dynamic models can be solved analytically, and the results represented graphically. However, simple models do not usually exist in large systems and, therefore, numerical methods are used.

Numerical methods involve the use of digital computer simulations. While this can be an expensive undertaking, it provides advantages of timeliness, versatility, and ease of parameter variability, and is usually less costly than building and testing an actual system. Development of a computer simulation is performed in the steps discussed below [2]:

a. Problem Definition - The objectives and scope of the study must be clearly defined in unambiguous terms. Any limitations should be identified. A specification should be prepared that defines the functions to be performed by the simulation, and all performance requirements which it must satisfy to meet study objectives. Each requirement must be testable after the simulation is developed.

b. Math Model Formulation - The equations which define functional performance are then developed and a flow chart is prepared which shows all processes, data paths, decision points, files, inputs, and outputs.

c. Program Construction - Software

modules are gathered or new programs are coded, assembled, and checked out to ensure satisfactory integration.

d. Verification - A test program is planned and conducted which demonstrates that the simulation meets the requirements of its specification.

e. Experimental Design - Appropriate scenarios and input conditions are developed for the case under study. These should include end or limit conditions for which the outcome is known.

f. Validation - Validation is different from verification in that it demonstrates that the model portrays the actual situation and interacts properly with the real world. The situations chosen for validation must have a known outcome.

Once validated, the simulation may then be employed to establish and optimize parameters and to verify the selected design. Development of simulations is an iterative process, with changes in requirements and programs being incorporated as experience is gained. Simulations are classified as either continuous or discrete. In continuous programs, independent variables are a function of time. This is useful in establishing the behavior of the system during transient responses to perturbations. Discrete models change state only in steps; interstate transients are not considered.

A discrete model often results from disruption of the system status caused by the allocation and reallocation of resources within the system. Queueing is an important consideration in systems that can be described by discrete event models. Discrete models can be further subdivided into process and event oriented models. A process oriented model views the world as a set of fixed facilities which are used to service active transactions that are created and moved through the system. An event oriented model views the world as a series of events which occur at scheduled times and searches for facilities to process them.

7.3 DRAWINGS AND LISTS

Systems engineering prepares and audits system level design documentation which is placed under configuration management. The initial definition of components, provided by systems engineering, is a listing which identifies all components in the system, their numbers, and intended use. This is used by the design engineering organization as the basis for equipment and weight lists. Eventually, these will become a parts list to identify and track hardware and computer software items.

In the case of a spacecraft, the primary system level data developed by the design engineering organization may be the vehicle inboard profile, envelope drawings, and facility layout drawings. The inboard profile drawing will establish the location of all components on the vehicle and assure that adequate space is available. The envelope drawing will show the coordinates, overall physical dimensions, view angles, and equipment attachment points and serve as the basis for interface requirements. The facility layout drawing will determine facility space requirements for equipment and ensure that adequate area is available for personnel operations/ maintenance.

7.4 REFERENCES

1. MIL-STD-499A, "Engineering Management".

2. Conklin, J. "System Simulation". Space System Design
and Development Seminar, San Jose State University,
1981.

3. Gordon, G. "System Simulation". Englewood Cliffs, NJ:
Prentice-Hall, 1969.

CHAPTER 8

EVALUATION AND DECISION: TRADE STUDIES

8.1 INTRODUCTION

Trade studies are performed throughout development as an essential part of the systems engineering process outlined in Chapter 5 of this guide. Trade studies are controlled by systems engineering to integrate and balance all design-for and engineering specialty requirements.

As a formal decision analysis method, trade studies are used to solve any complex problem where there is more than one selection criterion, and provide documented decision rationale for review by a higher authority. These analyses are equally necessary for establishing system configurations and for accomplishing detailed design of individual components. The trade study method is equally applicable to budgeting, source selection, test planning, logistics development, production control, and design synthesis.

The role of trade studies evolves with the acquisition process, as shown in Figure 8-1. During the Concept Exploration/ Definition (C/E) and the Concept Demonstration/ Validation (D/V) phases, trade studies are used to establish the system configuration. During Full Scale Development (FSD), trade studies are employed to assist in

Figure 8-1
Trade-Off Analysis in the Acquisition Process

ACQUISITION PROCESS PHASE	TRADE-OFF ANALYSIS FUNCTION*
MISSION AREA ANALYSIS	• PRIORITIZE IDENTIFIED USER NEEDS
CONCEPT EXPLORATION	• COMPARE NEW TECHNOLOGY WITH PROVEN CONCEPTS • SELECT CONCEPTS BEST MEETING MISSION NEEDS • SELECT ALTERNATIVE SYSTEM CONFIGURATIONS
DEMONSTRATION/ VALIDATION	• SELECT TECHNOLOGY • REDUCE ALTERNATIVE CONFIGURATIONS TO A TESTABLE NUMBER
FULL SCALE DEVELOPMENT	• SELECT COMPONENT/PART DESIGNS • SELECT TEST METHODS • SELECT OT&E QUANTITIES
PRODUCTION	• EXAMINE EFFECTIVENESS OF ALL PROPOSED DESIGN CHANGES • PERFORM MAKE-OR-BUY, PROCESS, RATE, AND LOCATION DECISIONS

* IN ADDITION, TRADE STUDIES ARE USED TO BALANCE CONSIDERATIONS SUCH AS PRODUCIBILITY, TESTABILITY, SURVIVABILITY, COMPATIBILITY, SUPPORTABILITY, STABILITY, AND RELIABILITY DURING EACH PHASE OF THE ACQUISITION PROCESS. EACH SOURCE SELECTION IS CONDUCTED USING TRADE-OFF ANALYSIS METHODS.

selecting component/part designs. Later, as the system enters the Production phase, trade studies support make-or-buy, process, rate, and location decisions as well as examination of all proposed design changes. Control of systems engineering trade studies throughout the acquisition cycle (to balance considerations such as producibility, testability, survivability, compatibility, stability, supportability, and reliability with cost, schedule, and performance objectives) is the primary means of executing systems engineering responsibilities. Some applications of the trade study method in the systems engineering process are indicated in Figure 8-2.

8.2 BASIC METHODOLOGY

The trade-off analysis methodology provides a structured, analytical framework for evaluating a set of alternative concepts or designs. Figure 8-3 shows the basic steps of the analysis, which are outlined in the following paragraphs.

8.2.1 Define Objectives and Requirements

Analysis objectives and requirements must be expressed in precise, explicit terms to serve as the basis for sound decisions. They should define the need, the user, and the availability of resources bounding the scope

Figure 8-2
Trade-Off Analysis in the Systems Engineering Process

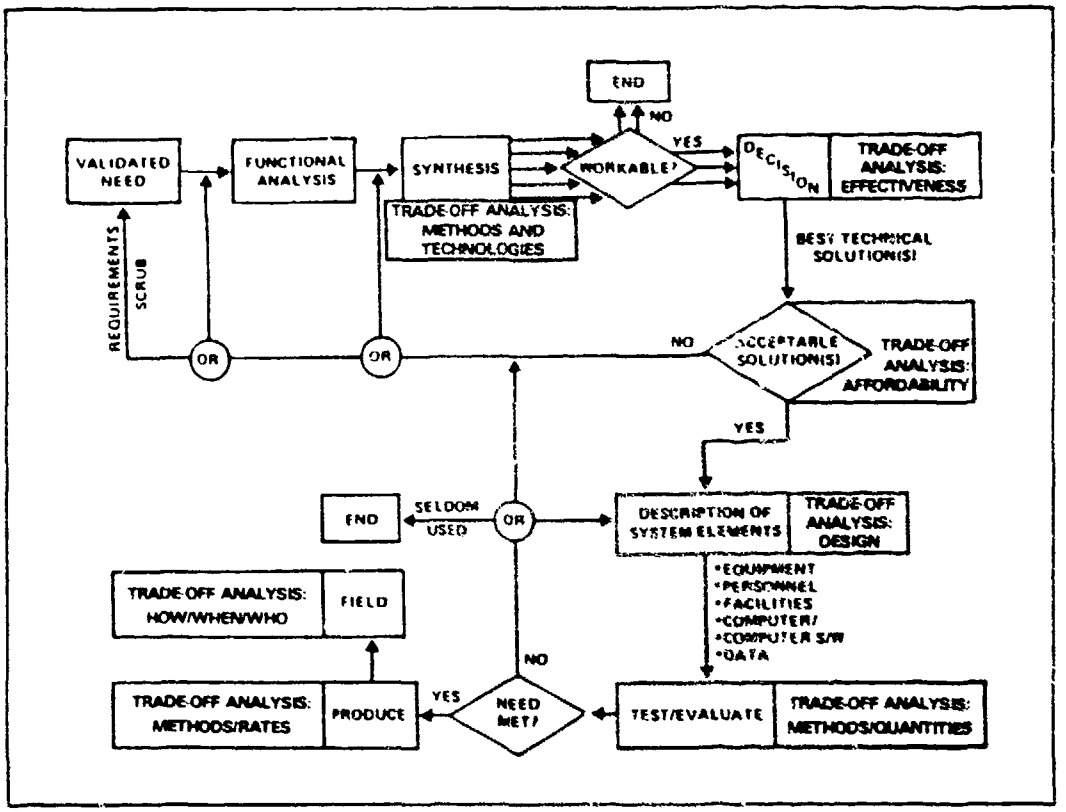
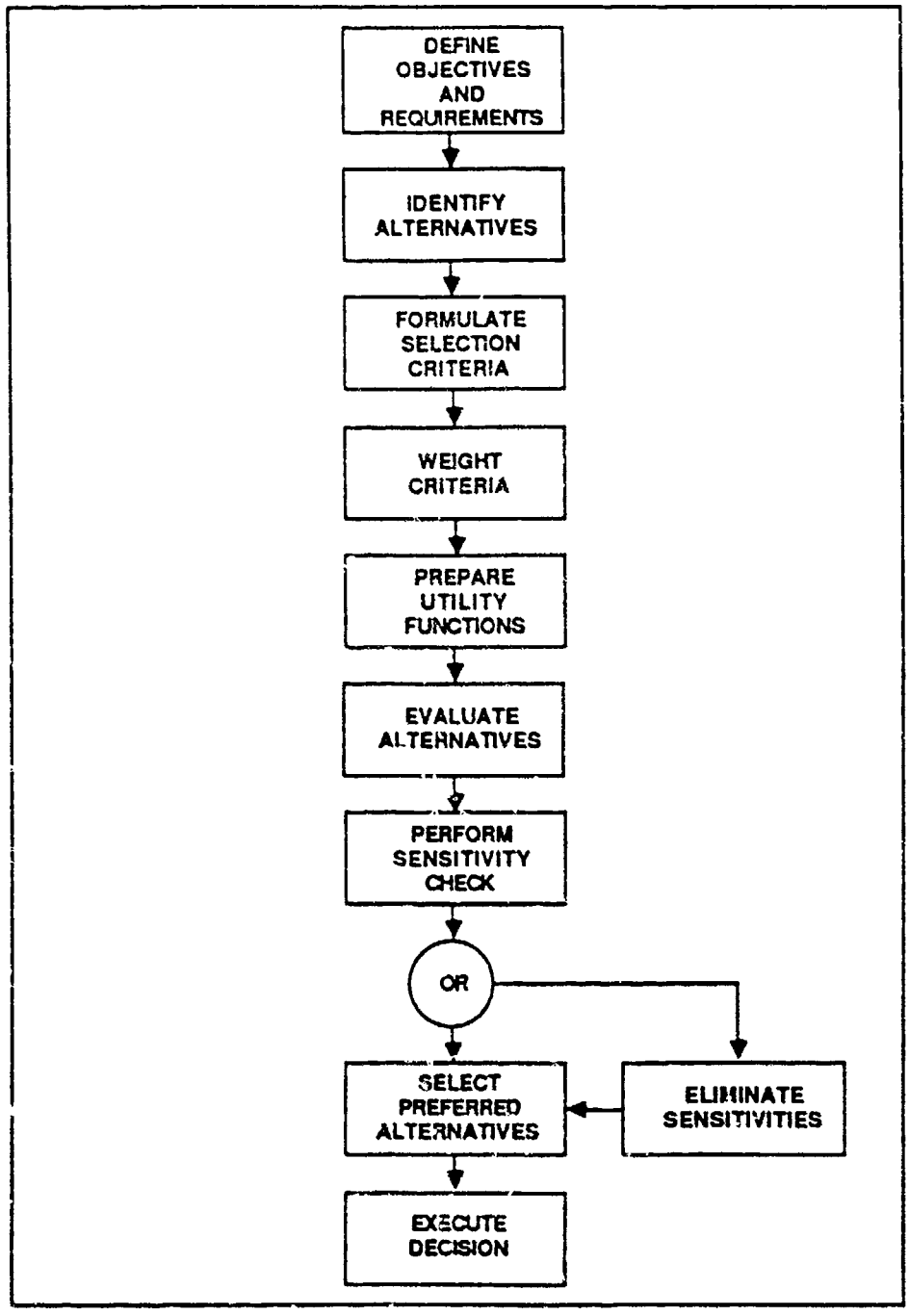


Figure 8-3
Trade-Off Analysis Methodology



of the analysis. The source for these objectives will be systems engineering documentation such as the Functional Flow Block Diagram and Requirements Allocation Sheet (FFBD and RAS). This will provide a firm foundation for identifying the range of alternatives and the decision criteria.

Examples of partial objectives/ requirements for a trade-off study involving design of the aft crane configuration on a logistic ship for the Navy (see Reference [3]) are:

a. Loading must be accomplished in less than 48 hours.

b. The ship must have the capability to carry out roll-on/roll-off (RO/RO) operations in-stream as well as pierside.

c. Discharge time at pierside must not exceed 24 hours.

8.2.2 Identify Alternatives

Alternatives for consideration will be either predetermined (in the case of a design competition, they will be the various proposed designs) or developed specifically for the analysis. Candidate alternatives may be the product of systems engineering synthesis activities and represent existing (standard), modified, or original designs. Candidate alternatives should reflect the widest possible range of distinctly different solutions if the overall goal of optimized system design is to be achieved.

Next, candidate alternatives identified through unconstrained synthesis or brainstorming may be screened based on their ability to solve the problem. This ensures that the analysis effort does not waste time on nonproductive solutions. A second screening may be performed on the basis of attainability/affordability: Are the candidate alternative solutions achievable within time and budgetary constraints?

Remaining candidate alternatves become the decision alternatives. These alternatives are described fully and carefully. Sufficient detail must be available to judge the relative worth of each workable, attainable alternative. If an insufficient number of candidate alternatves survives the screening process, the study constraints should be reexamined and all candidate alternatives rescreened, or the synthesis and possibly functional analysis activity must be reinitiated. In the example given in Paragraph 8.2.1, three configuration alternatives were considered:

a. Configuration 1 - Two 70-ton gantry cranes at Location 1

b. Configuration 2 - Two 50-ton revolving boom cranes at Location 2

c. Configuration 3 - Two 50-ton revolving boom cranes at Location 3.

8.2.3 Formulate Selection Criteria

Selection criteria are standards for judging achievement of required operational effectiveness/suitability characteristics, or resolution of technical or operational issues. The criteria may include quantitative goals (desired value of the attribute), where possible, and thresholds beyond which the characteristic is unsatisfactory (specification

limits). Good selection criteria must:

a. Differentiate meaningfully between alternatives without bias

b. Relate directly to purpose of the trade-off analysis, including established requirements and high-interest concerns

c. Be stated as broadly as possible

d. Be able to be measured or estimated at reasonable cost

e. Be independent of each other at all levels

f. Be universally understood by evaluators.

Selection criteria may be drawn from systems engineering documentation based on program requirements; military and department guidance and standards; and design-for and specialty requirements. These sources vary in importance based on the stage of program development and design maturity. Typical sources for selection criteria at each phase of the acquisition process are shown in Figure 8-4. These or similar program documents typically provide performance, schedule and cost ranges/ thresholds, and background/ decision information. Regardless of the sources used and the advice obtained, final selection must be made by the decision maker. The value of the trade-off analysis effort is proportional to the decision maker's ability and willingness

Figure 8-4
Sources of Design Trade Study Decision Criteria

MISSION AREA ANALYSIS	. SERVICE MISSION ROLES . NATO RATIONALIZATION, STANDARDIZATION INTEROPERABILITY POLICIES
CONCEPT EXPLORATION	SYSTEM PERFORMANCE REQUIREMENTS . JUSTIFICATION FOR MAJOR SYSTEM NEW START . PROGRAM OBJECTIVES MEMORANDUM
DEMONSTRATION/VALIDATION	. SEMP . SYSTEM CONCEPT PAPER . TEST AND EVALUATION MASTER PLAN . TPM PLAN . PLANNING, PROGRAMMING, AND BUDGETING SYSTEM DOCUMENTATION
FULL SCALE DEVELOPMENT	. SEMP . ILSP . DECISION COORDINATING PAPER . TPM . INTEGRATED PROGRAM SUMMARY . PLANNING, PROGRAMMING, AND BUDGETING SYSTEM DOCUMENTATION
PRODUCTION	. EXISTING TECHNICAL MANUALS . ILSP . SECDEF DECISION MEMORANDUM . PRODUCTION ENGINEERING PLAN . PPBS . FIELDING PLAN

to include all objective and subjective decision criteria. Regular, efficient guidance on appropriate decision criteria is one of the primary products of the systems engineering organization.

8.2.4 Weight the Criteria

Selection criteria are weighted by the decision maker according to their relative importance in determining the effectiveness of alternatives. To ensure the objectivity of the subsequent analysis, weighting factors developed by the decision maker may be withheld from the analysts who do the performance evaluation.

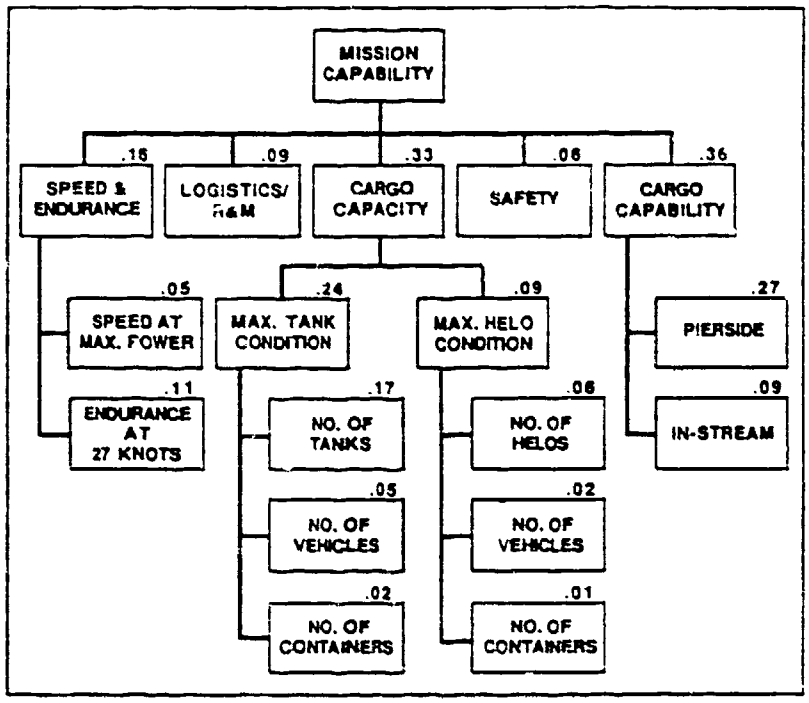
Weighting follows a logical breakdown such as the one illustrated in Figure 8-5 for a ship design program. Essentially, the numerical scale used is coincidental, provided that it is consistently distributed down the criteria tree. In this example, criteria are classified by their relative contribution to mission capability including speed/endurance, logistics, cargo capacity, safety, and cargo capability. First, effectiveness measures are examined for their contribution to objectives for the system; then each criterion is weighted according to its perceived contribution to the effectiveness measures. The extent of the breakdown required is determined by:

a. The level at which performance evaluation is possible

b. The level at which separate performance specifications have been established.

Numerical weights are given to reduce the effect of evaluator bias on the analysis. Numerical weighting allows the decision maker to obtain an objective assessment of

Figure 8-5
Sample Criteria Weighting



the alternatives. In addition, numerical treatment facilitates comparison among criteria that are not related. For instance, in this example, cargo capacity is twice as important as speed and endurance, and only slightly less important than cargo capability. The advantages in relative simplicity, efficiency, and objectivity of this approach far exceed the effort required to assign numerical weights. Decision makers who claim that they cannot assign numerical weights to the criteria should realize that decisions are based on quantified criteria whether that quantification is subconscious (unsystematic and undocumentable) or objective/ numerical (systematic and documentable).

Where a program maintains an overall system effectiveness model and has operational data, this weighting process can be very objective. In cases where such a foundation is not available, decision support techniques can be used to render subjective evaluations more reliable. In the ship example used in this chapter, the authors used the analytic hierarchy process (see Reference [3]) to set criteria weights using a paired comparison technique. Engineers and managers from the design team were asked to prepare data input sheets that compared attributes at each level on a one-to-one basis. A typical input sheet is shown in Figure 8-6. Data were entered into a computer for analysis, consolidation, and normalization into matrix form. The mathematical technique of eigenvector analysis was then applied to the normalized matrix to determine the relative weightings of all components at each level. Once the weighting factors of all elements of the hierarchy were derived, the "contributing weight" of any one attribute could be calculated by multiplying the weights of its associated category headings by its weighting factor. Data from respondents were summarized and, with minor adjustments, resulted in the priorities shown in Figure 8-5.

Figure 8-6
Sample Prioritization Input Sheet

SL-7 CLASS CONVERSION TRADE-OFF STUDIES
PRIORITIZATION SURVEY

WHAT IS YOUR OPINION AS TO WHICH MISSION CAPABILITY ATTRIBUTE IS MORE IMPORTANT TO MISSION SUCCESS?

MISSION ATTRIBUTE		MISSION ATTRIBUTE
CARGO CAPACITY	9-8-7-6-5-4-3-2-1-2-3-4-(5)-6-7-8-9	CARGO CAPABILITY
CARGO CAPACITY	9-8-7-6-(5)-4-3-2-1-2-3-4-5-6-7-8-9	SPEED AND ENDURANCE
CARGO CAPACITY	9-8-7-6-5-(4)-3-2-1-2-3-4-5-6-7-8-9	LOGISTICS/R&M
CARGO CAPACITY	9-8-7-6-5-(4)-3-2-1-2-3-4-5-6-7-8-9	SAFETY
CARGO CAPABILITY	9-8-7-(6)-5-4-3-2-1-2-3-4-5-6-7-8-9	SPEED AND ENDURANCE
CARGO CAPABILITY	9-8-7-(6)-5-4-3-2-1-2-3-4-5-6-7-8-9	LOGISTICS/R&M
CARGO CAPABILITY	9-(8)-7-6-5-4-3-2-1-2-3-4-5-6-7-8-9	SAFETY
SPEED & ENDURANCE	9-8-(7)-6-5-4-3-2-1-2-3-4-5-6-7-8-9	LOGISTICS/R&M
SPEED & ENDURANCE	9-(8)-7-6-5-4-3-2-1-2-3-4-5-6-7-8-9	SAFETY
LOGISTICS/R&M	9-8-7-6-5-4-3-2-(1)-2-3-4-5-6-7-8-9	SAFETY

This technique of pairwise comparisons has been shown to give more repeatable weightings than direct estimation of the relative attribute priorities.

8.2.5 Prepare Utility Functions

Although not necessary for every trade study application, utility curves are a good technique for translating diverse criteria to a common scale. For example, in the trade study illustrated, how does one compare speed (in knots) with endurance (in nautical miles), or cargo capacity (in number of vehicles) with cargo capability (in hours at dock)? Utility functions provide this mediating capability. Briefly, utility curves assume that changes in the performance associated with a particular criterion can be translated into a utility score. This utility score may range from 0 to 1, with the lower bound on the possible value of an attribute being assigned a utility of 0, and the upper bound being assigned a utility of 1. The range of the utility curve encompasses the range of acceptable or realistic alternatives. For example, if it were determined that the baseline design would allow a top speed to range anywhere from 27 to 33 knots, 27 knots would be assigned a utility curve value of 0 and 33 knots would be given a utility curve value of 1. Utility curves may be developed using engineering judgment or a more quantitative approach, such as assessment of the probability of the ship's survival during a mission as a function of its speed. Figure 8-7 illustrates one theoretical utility curve for ship speed. The utility value of an attribute is multiplied by the contributing weight of the attribute to determine the change in overall mission capability of the ship. Figure 8-8 shows other sample utility curves.

Reference [1] makes the distinction between three approaches to establishing utility scales: 1) absolute scaling, 2) ratio scaling, and 3) relative scaling. The examples used in this chapter all infer the use of absolute scales. This approach is the most desirable for military system evaluation. It assumes that by analysis or initiative, it is

Figure 8-7
Sample Utility Curve for Ship Speed

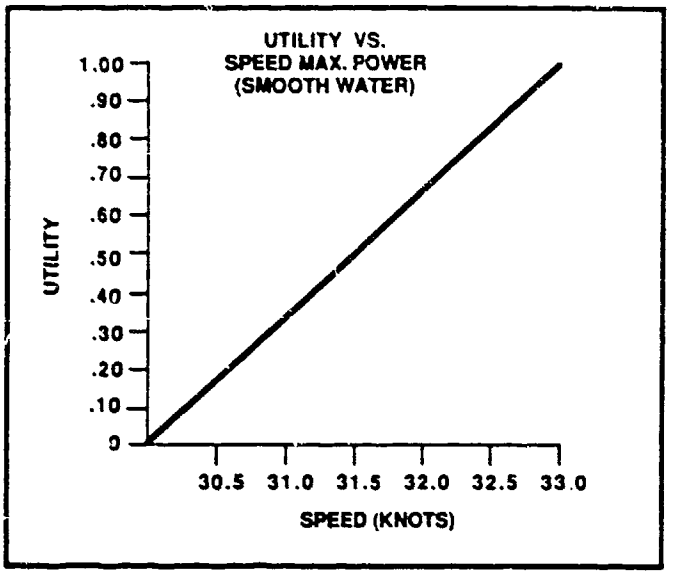
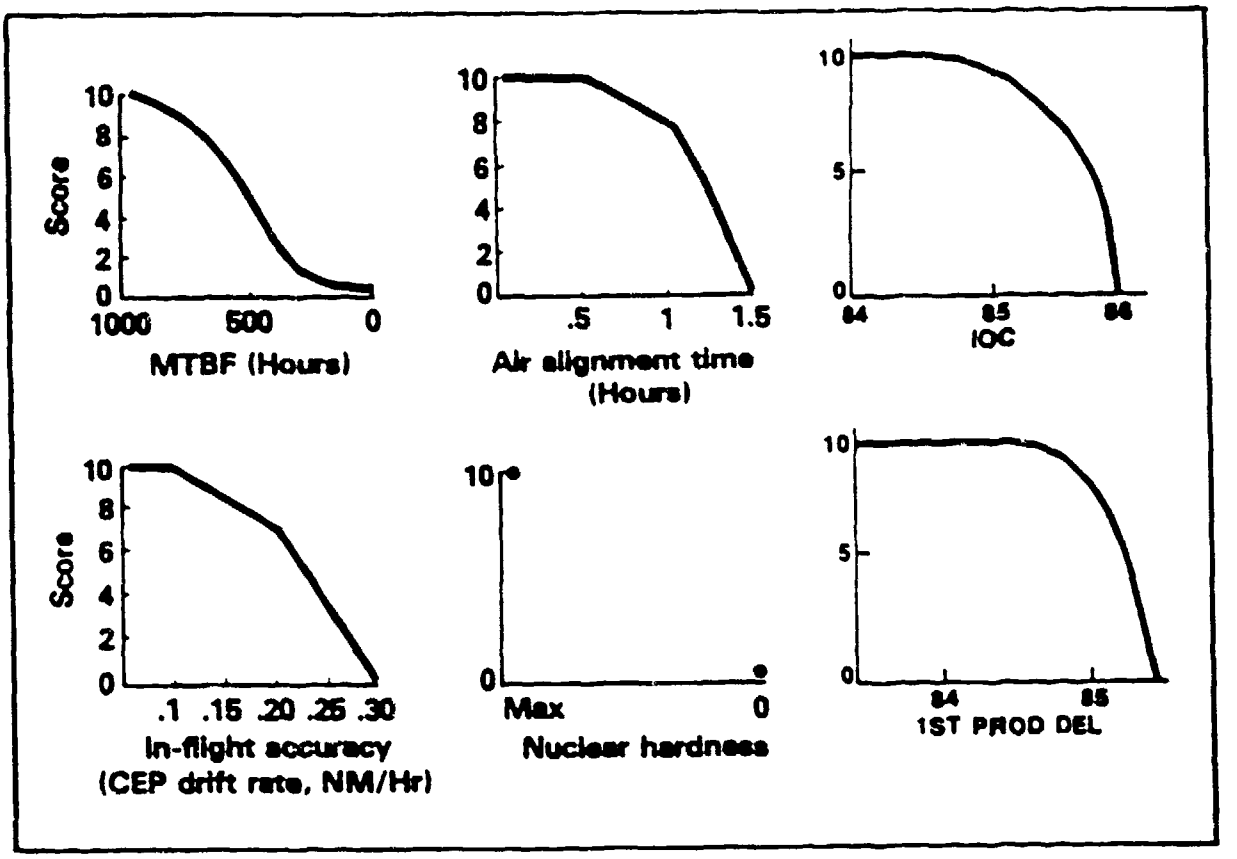


Figure 8-8
Sample Utility Curves



possible to conceptualize a "perfect" system and to predict a level of performance with respect to each attribute for each alternative being evaluated.

In cases where an attribute is difficult to quantify or measure, the evaluation might establish a ratio scale (see Reference [1]) or use the analytic hierarchy process (see Reference [2]) to establish a relative scale for utility values. The ratio and relative scaling approaches identify the "best" alternative through a structured comparison of alternatives. These approaches are most valuable in considering nontechnical parameters (such as cost, development time, political saleability) where only subjective (high, medium, low) evaluation is possible. For example, if safety was an essential trade study criterion, it could be included as a relatively scaled attribute using a paired comparison process and scaling methodology similar to that suggested in Reference [2].

Utility curves for a given trade study must use consistent scales (e.g., between 0 and 1) so as not to inadvertently weight the scores. These models also must assume the independence of criteria. The "zero point" of each curve indicates the level of performance which no longer provides value to system performance or effectiveness. The

specification values, since minimum acceptable values are usually the cut-off beyond which alternatives are "not worthwhile to pursue," rather than "without value."

Graphic utility curves are not necessary for every criterion. Where linear relationships are assumed between utility and performance, simple tables can be established. Tabular scoring plans could replace graphic charts for any criterion; however, some fixed plan for scoring performance evaluations must be established before the evaluations are conducted.

8.2.6 Evaluate Alternatives

After utility functions have been established, the performance of each alternative is estimated with respect to each criterion. Performance estimates are produced by evaluators from testing, vendor sources, parametric analysis, simulation, experience, comparison, or other available, affordable, and dependable methods.

The scoring plan represented by the utility curves is then used to convert these performance estimates into effectiveness measures by assigning a score for each performance level. For example, in Figure 8-7, shown previously, an alternative evaluated as having an expected speed of 31.5 knots would receive a score of .50, while an expected speed of 33 knots would receive a score of 1.0.

Scores are collected and summarized in tabular form. A table is developed which shows assigned scores on the same numerical scale for all criteria and all alternatives. The decision maker applies criteria weights to the evaluation results to complete the effort. Figure 8-9 shows a sample weighted summary

Figure 8-9
Sample Weighted Summary Table

CRITERIA [WEIGHT]	ALTERNATIVES									
	ALT 1		ALT 2		ALT 3		ALT 4		ALT 5	
	SCORE	WEIGHTED SCORE	SCORE	WEIGHTED SCORE	SCORE	WEIGHTED SCORE	SCORE	WEIGHTED SCORE	SCORE	WEIGHTED SCORE
A [15]	3.1-3.5	46.5-52.5	4.2-5.9	63-88.5	6-6.5	90-97.5	3.5-5.2	52.5-78	4-5.5	60-82.5
B [20]	3.9-4.6	78-92	7.8-8.2	156-164	8.9-9.2	178-184	6.4-6.9	128-138	7.6-8.1	152-162
C [10]	5.2-6	52-60	4.3-6	43-60	7-8.2	70-82	7.3-8.5	73-85	9.2-9.5	92-95
D [35]	9-9.5	315-332.5	7-7.3	245-255.5	8.5-9	297.5-315	9.7-9.9	339.5-346.5	6.7-7.2	234.5-252
E [20]	5-6.7	100-134	3.5-4.5	70-90	5-6	100-120	6.9-7.2	138-144	7.8-8.2	156-164
TOTAL		591.5-671		577-658		735.5-798.5		731-791.5		694.5-755.5

Figure 8-10
Aft Crane Study Weighted Summary Table

Trade Study No. A1 Criteria	Priorities		Priorities							
			Baseline		Config. 1		Config. 2		Config. 3	
			Utility	Wtd Utility	Utility	Wtd Utility	Utility	Wtd Utility	Utility	Wtd Utility
—Pierside		0.74	0.5	0.37	0.5	0.37	0.5	0.37	0.5	0.37
—In-stream		0.26	0.487	0.1266	0.487	0.1266	0.487	0.1266	0.215	0.0559
Cargo capability	0.36			0.1787		0.1787		0.1787		0.1533
No. of tanks		0.72	0.5	0.36	0.38	0.2736	0.5	0.36	0.5	0.36
No. of vehicles		0.21	0.788	0.1654	0.788	0.1654	0.687	0.1442	0.71	0.1491
No. of containers		0.07	0.6	0.042	0.6	0.042	0	0	0	0
—Max tank condition	0.74			0.4199		0.3559		0.3731		0.3757
No. of helos		0.71	0.5	0.355	0.5	0.355	0.5	0.355	0.5	0.355
No. of vehicles		0.22	0.162	0.0356	0.156	0.0343	0.08	0.0176	0.162	0.0356
No. of containers		0.07	0.856	0.0599	0.856	0.0599	0	0	0	0
—Max helo condition	0.26			0.1171		0.1168		0.0968		0.1015
Cargo capacity	0.33			0.1772		0.1560		0.1551		0.1578
—Speed: max power		0.29	0.49	0.1421	0.49	0.1421	0.49	0.1421	0.49	0.1421
—Endurance		0.71	1	0.71	1	0.71	1	0.71	1	0.71
Speed and endurance	0.16			0.1363		0.1363		0.1363		0.1363
Logistics/R&M	0.09		0.5	0.045	0.4	0.036	0.6	0.054	0.6	0.054
Safety	0.06		0.5	0.03	0.5	0.03	0.5	0.03	0.5	0.03
Mission capability				0.3673		0.5371		0.5542		0.5314
Cost (millions)				60		65.72		58.48		58.58
Cost/capability ratio				105.7537		122.3509		105.5156		110.2165

table. The weighted summary table that was used in the study in Reference [3] is included as Figure 8-10. It shows a slightly different format from Figure 8-9.

8.2.7 Perform Sensitivity Check

A sensitivity analysis must be performed to determine the value of results to the decision maker. Where the total weighted scores of several alternatives are proximate, a small change in the estimated performance of any alternative against any criterion may change the decision. This is especially important where performance estimates are developed without benefit of operational data. In these instances, it may be useful to indicate a range of estimated performance values having a known confidence level which can be transferred to the weighted scores.

The results of the trade study presented in Figure 8-9 illustrate the effect of overlapping ranges on the analysis. The preferred alternative cannot be determined in this example since no single alternative scores higher than all others for every value within its range. Simply stated, although Alt 3 has the highest absolute numerical score and the highest average score, there are values of Alts 4 and 5 that are potentially higher than given values of Alt 3.

In the example in Figure 8-9, trade study results allow only the elimination of Alts 1 and 2 from further consideration. Additional information will be needed to differentiate meaningfully between Alts 3, 4, and 5. Further analysis may later show Alt 3 in the range of 736 to 740, Alt 4 in the range of 742 to 746, and Alt 5 in the range of 752 to

755, which would indicate Alt 5 as the clearly preferred alternative.

Where the accuracy limits of the performance evaluation affect the decision, several options are available to the decision maker:

a. Delay the decision until additional information is available.

b. Acquire additional data or refine analysis to reduce uncertainty.

c. Review criteria and weights for modification.

d. Acquire insurance/back-up capability (elect parallel development plans).

8.3 TRADE-OFF ANALYSIS APPLICATIONS

In applying trade-off analysis methods to actual program decisions, several limitations of the analysis methodology are encountered.

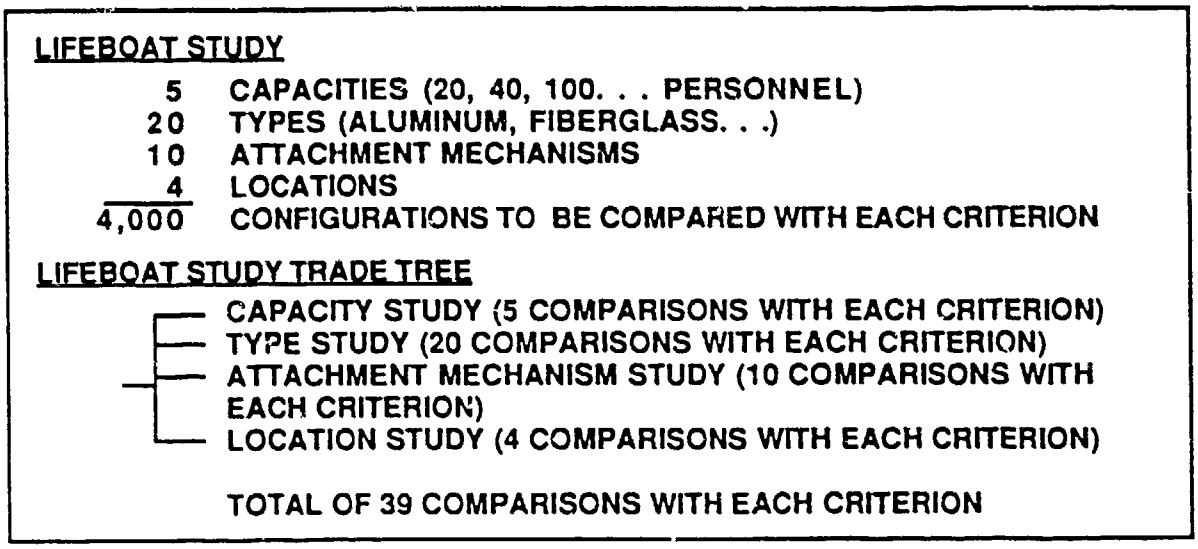
As discussed in Section 8.2, there is a reluctance to use trade-off analyses when criteria are not conducive to objective evaluations. Studies including, for example, parameters such as credibility, national defense, and political saleability of various alternatives, are not always seen as amenable to a numerical performance measurement scheme. Although the use of the trade-off analysis in these situations is not as straightforward, the trade-off analysis can replace the decision maker's intuitive balancing of these factors with an explicit methodology.

Trade-off analysis is used in source selection. As part of the source selection plan included in the solicitation, evaluation criteria and the relative importance of these criteria are explicitly stated. Trade-off analyses used in source selection must comply with Federal Acquisition Regulation requirements, Program Manager's decisions, and service administrative procedures. The program office must document the criteria and weighting information used, as well as evaluation methods and confidence levels, as part of the source selection approval documentation. Further guidance on the source selection plan is given in DoDD 4105.62 [4].

The limitations of the trade-off analysis process arise from three sources: 1) the validity of the results is limited by the quality of data and evaluators, 2) the selection of criteria, weighting schemes, and utility curves can bias the analysis, and 3) the number of alternatives that can be evaluated is limited by the analysis burden.

Handling large trade-off analyses with many alternatives requires use of a "trade tree." The trade tree uncouples an oversized trade-off analysis into several smaller studies. For example, consider the choice of lifeboats for carrying 200 personnel (see Figure 8-11). If each of the 4,000 alternatives needed to be evaluated against each selection criterion, an enormous evaluation effort would be required. Instead, the analysis can be broken into four smaller studies: a capacity study; a boat type study; an attachment mechanism study; and a mounting location study. Each smaller study would then involve evaluating its respective alternatives against all

Figure 8-11
Use of Trade Tree to Uncouple Trade-Off Analyses



applicable criteria. As a result, only 39 comparisons would be needed for each criterion.

8.4 TRADE STUDY REPORTS

Trade Study Reports (TSRs) are used by all decision-making levels from the systems engineering organization through the government program office, Program Manager, and headquarters. TSRs document the decision process and are used to correlate characteristics of alternative solutions to the requirements and constraints which establish the selection criteria for a specific trade study area. Each report documents the rationale used in the decision process and should present risk assessment and risk avoidance considerations. At a minimum, each report should contain the analysis result and rationale, a description of the alternatives considered, the selection criteria and weights, and the results of the sensitivity analysis. Report. The report format should be coordinated between the program office and the contractor by tailoring TSR requirements using the streamlining methodology addressed in Chapter 10 of this guide.

TSRs are important contributors to the formal technical review process. As with all systems engineering documentation, the focus and level of detail changes as a program moves through the acquisition life cycle. For example, in conjunction with the System Requirements Review (SRR), available TSRs might cover system cost effectiveness and life cycle cost. During Preliminary Design Reviews (PDRs), trade studies might be

equipment concepts related to specific functions such as fail-safe concepts, fault isolation, or target acquisition. The Critical Design Review (CDR) may include trade studies for selection of manufacturing processes. Trade studies can provide valuable support to many specialty areas, such as in the evaluation of risk alternatives (see Chapter 15 of this guide for more detailed discussion of risk analysis and management). It is important for all trade studies on a system to use common criteria and common relative weighting whether they are for risk management, reliability and maintainability, integrated logistic support, or other specialty areas. This will ensure a common baseline for all decisions.

8.5 RISK TEMPLATE: TRADE STUDIES (DoD 4245.7-M)

DoD 4245.7-M [5] contains templates addressing sources of risk during the transition from development to production. Each template contains a description of the area of risk, an outline for reducing risk, and a time line that shows the risk area's relation to the system acquisition cycle. This chapter, as other chapters in this guide, incorporates the template provided by DoD 4245.7-M [5]. The following is an extract from DoD 4245.7-M [5] on the subject of trade studies.

Trade studies are essential elements of material acquisition programs, not only in defining concepts that best meet mission needs, but also in fine-tuning selected concepts during the design process. Concept validation may not be complete at the beginning of Full Scale Development; however, there is the expectation that significant conceptual problems can be resolved during the design process. In addition, reducing production risk frequently is not a trade study criterion. DoD 4245.7-M [5] recommends the following outline for reducing risk:

a. Concepts representing new technology untested in the production environment are validated fully before FSD.

b. Trade studies during the design process are oriented towards reducing product risk, by such means as design simplification, design for compatibility with production processes, design for ease of both factory testing and built-in test, and design for supportability and readiness.

c. Early in the design phase, full consideration is given to standard components that have been developed and can meet the mission requirements (such as standard avionics or egress seats).

d. A quantitative trade parameters list is developed and standardized across all design, manufacturing, and quality disciplines as a priority task early in the Research, Development, Test and Evaluation (RDT&E) program.

e. Trade study alternatives are documented and preserved formally in design review documentation to ensure system engineering traceability to design characteristics downstream.

f. Production transition trade studies are based on design and performance criteria as

weight factors for trade study decisions.

A broad spectrum of trade studies is initiated during the C/E phase. These trade studies continue on into FSD as a logical approach to selecting the best design once the mission profile and design requirements have been specified. The final selection and fine tuning of the design approach must consider such factors as producibility and operational suitability as well as performance, cost, and schedule.

8.6 SUMMARY

Evaluation and decision occur at many points in each phase of the acquisition life cycle. Although this chapter has focused on one approach to the trade study process, in reality there are many approaches and techniques. The "best" approach for analysis of logistic alternatives to support an Integrated Logistic Support Plan (ILSP) in the D/V phase may be totally different than the trade-off techniques best suited to trading reliability for maintainability, or the techniques required to develop a software module. However, all trade studies seem to share certain desirable characteristics. These characteristics are summarized in Figure 8-12 as a management checklist for evaluation of trade study planning and/or reports. Trade studies take place throughout the acquisition cycle, but effective baselining inhibits endless costly cycles of revisiting confirmed decisions. A more comprehensive discussion of baselining is contained in Chapter 11 of this guide.

8.7 REFERENCES

1. Donnell, M. L. and Ulvila, J. W.; "Decision Analysis of Advanced Scout Helicopter Candidates", DTIC Technical Report, Defense Logistics Agency, February 1980.

2. Saate, T. L.; "Analytic Hierarchy Process", McGraw-Hill, 1980.

3. Russon, L. and Streifer, S.; "A Systems Engineering Approach to Support Design of the Navy's SL-7/T-AKR Fast Logistics Support Ship Conversions." Marine Technology, July 1985.

4. DoDD 4105.62, "Selection of Contractual Sources for Major Defense Systems".

5. DoD 4245.7-M, "Transition from Development to Production".

Figure 8-12
Program Manager's Checklist for Review of
Trade-Off Planning and Studies

1. ARE ALL VIABLE ALTERNATIVES BEING EXPLORED?

   - IS EACH ALTERNATIVE CLEARLY DEFINED?
   - HAVE THE ALTERNATIVES BEEN PRESCREENED? HOW?
   - ARE AFFORDABILITY LIMITS ESTABLISHED? SOURCES?
   - CAN ALL OF THE SCREENED-OUT ALTERNATIVES BE DEFENDED?

2. ARE SELECTION CRITERIA IDENTIFIED?

   - ARE ALL SIGNIFICANT CRITERIA IDENTIFIED?
   - DO THE CRITERIA DISCRIMINATE BETWEEN ALTERNATIVES?
   - ARE THE CRITERIA MEASURABLE?
   - HAVE THE CRITERIA BEEN PRE-APPROVED?

3. IS THE CRITERIA WEIGHTING SYSTEM ACCEPTABLE?

   - ARE RATIONALES FOR CRITERIA WEIGHTS EXPLAINED?
   - ARE CRITERIA WEIGHTS CONSISTENT WITH GUIDANCE?
   - ARE CRITERIA WEIGHTS CONSISTENTLY DISTRIBUTED IN THE TREE?

4. ARE UTILITY (SCORING) CRITERIA DETERMINED?

   - IS A DEFENSIBLE RATIONALE ESTABLISHED FOR EACH CRITERION?
   - ARE CRITERIA DEVELOPED FROM OPERATIONAL MEASURES OF EFFECTIVENESS WHERE POSSIBLE?
   - DO ALL PLANS USE THE SAME NUMERICAL SCALE?
   - IS THE LOCATION OF THE "ZERO POINT" EXPLAINED?

5. ARE EVALUATION METHODS DOCUMENTED?

   - ARE TEST DATA RELIABILITY ESTIMATES (CONFIDENCE LEVELS) INCORPORATED?
   - ARE MODELS VALIDATED? WHEN? WHO?

6. HAS SENSITIVITY BEEN ESTIMATED?

   - ARE ERROR RANGES CARRIED THROUGH WITH WORST-ON-WORST CASE ANALYSIS?
   - HAVE THE EFFECTS OF CHANGES IN THE UTILITY CURVE SHAPES BEEN EXAMINED?
   - HAVE RATIONALES FOR THE LIMITS BEEN DEVELOPED?

CHAPTER 9
WORK BREAKDOWN STRUCTURES

9.1 INTRODUCTION

A work breakdown structure (WBS) is a product oriented family tree, composed of hardware, software, services, and data, which completely defines a program. The systems engineering process plays the critical role in identification of the product elements of the WBS. The WBS displays and defines the product(s) to be developed and/or produced and relates elements of work to be accomplished to the end product. The WBS is the foundation for:

a. Program and technical planning

b. Cost estimation and budget formulation

c. Schedule definition

d. Statements of work and specification of contract line items

e. Progress status reporting and problem analysis.

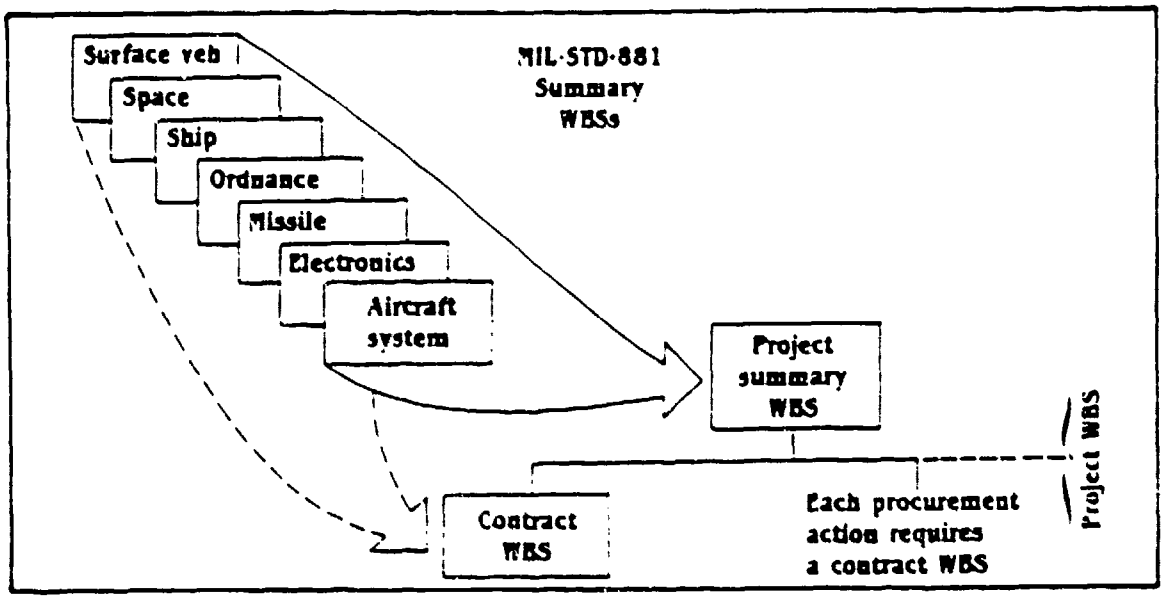
The WBS is essential in providing the capability for program management office (PMO) to exercise technical, schedule, and financial control of the program. Related performance measurement systems include the cost/schedule control system criteria (C/SCSC), Cost/Schedule Status Report (CSSR), Cost Performance Report (CPR), milestone measurement/ cost correlation (MM/CC), and technical performance measurement (TPM).

A WBS displays and defines the product(s) to be developed or produced and relates the elements to each other and to the end product. A WBS element is a discrete, identifiable item of hardware, software, data, or service. During the acquisition process, both the government and contractor have opportunities to "*tailor*" the WBS. This tailoring should have the goal of adding or deleting elements that will enhance the effectiveness of the WBS to satisfy both technical management and cost/ schedule management objectives. The WBS serves as a framework for the contractor's overall management system [1]. Four basic types of WBS formats are identified in MIL-STD-881A [2] and shown in Figure 9-1: 1) Summary WBS, 2) Project Summary WBS, 3) Contract WBS (CWBS), and 4) Project WBS.

9.1.1 Summary WBS

A summary WBS is a structure in which the upper three levels of the WBS are specified by MIL-STD-881A [2]. The summary WBS has a uniform element terminology, definition, and placement in the family tree structure. Appendices A through G of MIL-STD-881A [2] gives a three level WBS for each of the seven types of materiel

Figure 9-1
Relationship Among Types of WBSs



items procured by the Department of Defense (DoD) These summaries are for guidance only and need to be adapted to the needs of each program. The defense materiel items cited are: 1) aircraft systems, 2) electronics systems, 3) missile systems, 4) ordnance systems, 5) ship systems, 6) space systems, and 7) surface vehicle systems. The three levels included in a summary WBS are:

Level 1 - The entire system, also known as a defense materiel item; e.g., the Minuteman ICBM System, the LHA Ship System, or the M-109A1 Self-Propelled Howitzer System. Level 1 is usually directly identified in the DoD programming/ budget system either as an integral program element or as a project within an aggregated program element.

Level 2 - Major elements of the defense materiel item; for example, a ship, an air vehicle, a tracked vehicle, and activities such as systems test and evaluation (T&E), and data.

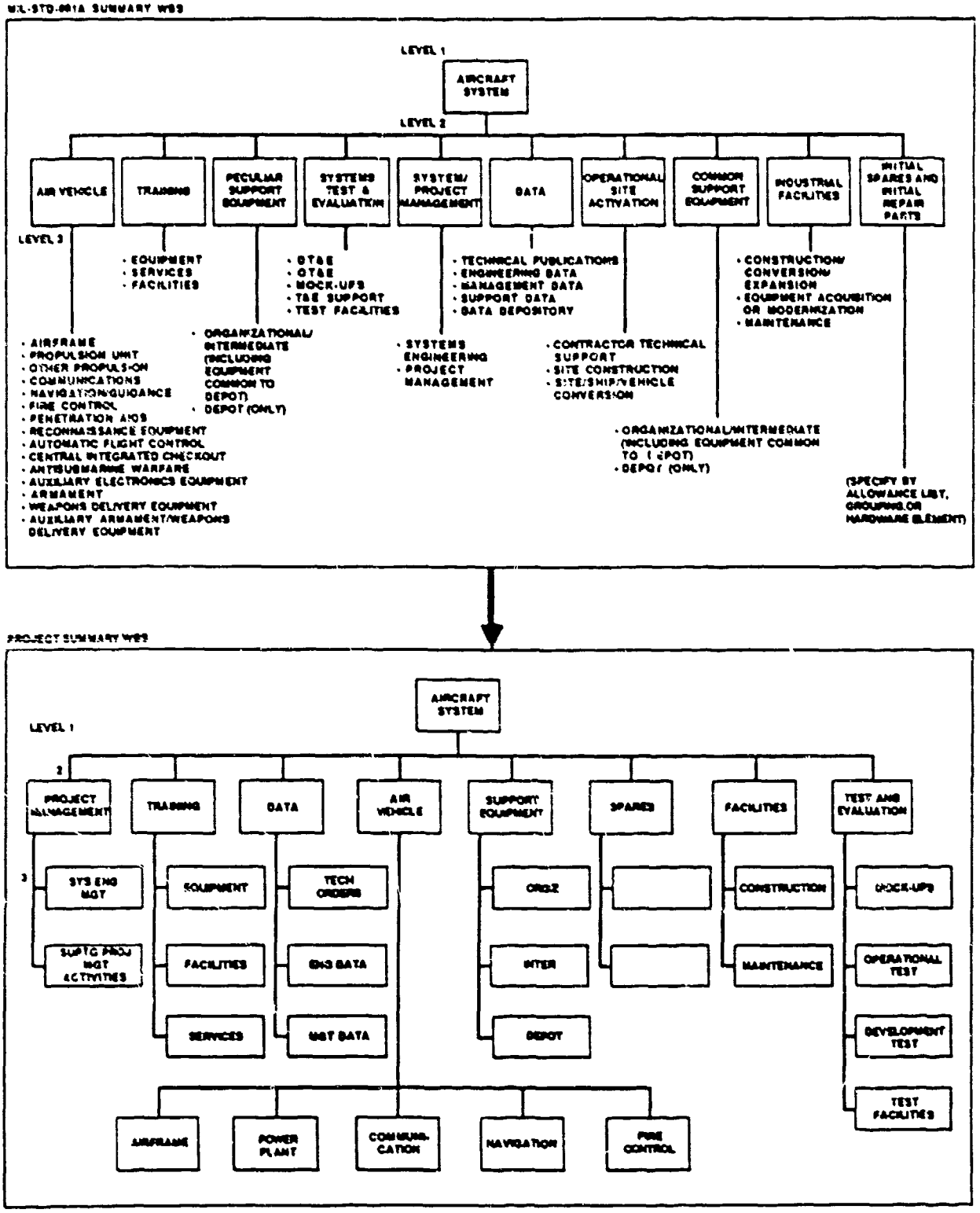
Level 3 - Elements subordinate to level 2 major elements; e.g., an airframe, the propulsion unit, or item of data or services such as development test and evaluation (DT&E) or technical publications.

The MIL-STD-881A [2] summary WBS for an aircraft system is shown in the top half of Figure 9-2.

9.1.2 Project Summary WBS

A project summary WBS is a summary WBS that is derived from MIL-STD-881A

Figure 9-2
Derivation of Project Summary WBS From Summary WBS



[2] but is tailored to the specific program. The project summary WBS is also specified to three levels of detail. A sample project summary WBS derived for a particular program is shown in the lower half of Figure 9-2.

9.1.3 Contract WBS

The CWBS is the complete WBS applicable to a particular contract or procurement action. It will generally contain the applicable portion of the project summary WBS plus any additional levels of detail necessary for planning and control.

The CWBS outlines program tasks and establishes their relation to program organization, configuration items, and objectives. It establishes a logical indentured framework for correlating perfromance, technical objectives, schedule, and cost, and ensures that all derivative plans contribute directly to program objectives. Development of the CWBS eliminates redundancy in task efforts and forms the basis for applying cost and schedule controls such as C/SCSC. Systems engineering plays a key role in the extension of the CWBS hardware elements. The dependence of hardware work package extension on the functional analysis, synthesis, and trade-off process provides correlation and traceability of the CWBS to system requirements. As an integrated data system, the systems engineering documentation also provides a common interface between specialty engineering efforts (e.g.; TPM, risk management, and integrated logistic support (ILS)) and program level activities (e.g.; project planning, cost/ schedule management, and engineering management). It also plays a key role in ensuring the correlation and traceability of WBS product elements.

9.1.4 Project WBS

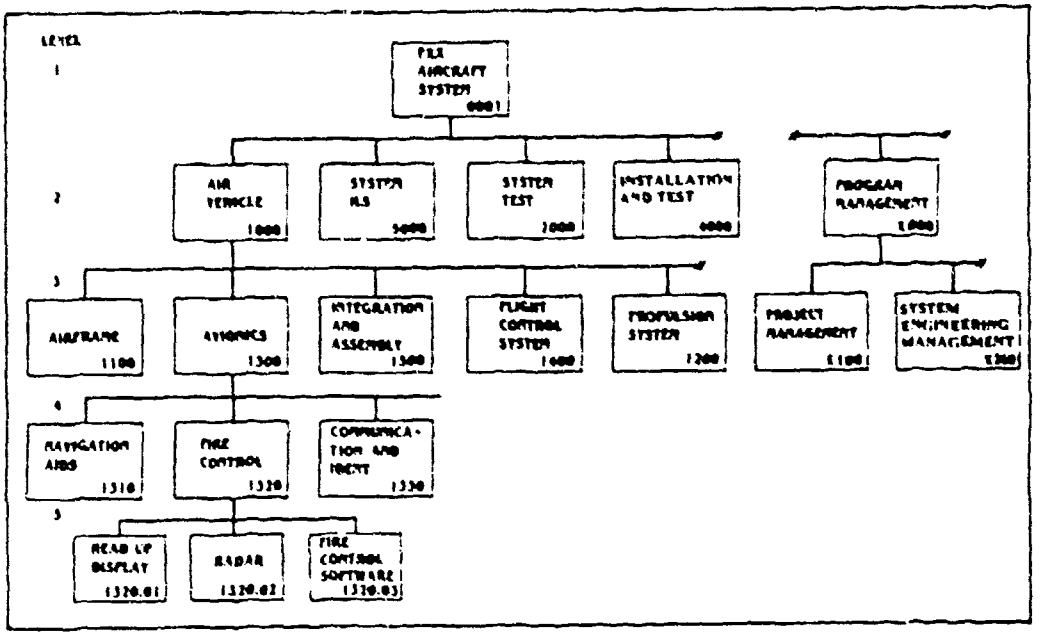
The project WBS is the complete WBS for the program. It contains all WBS elements related to the development and/or production of a defense materiel item and is formed by combining all the CWBSs in a program. The project WBS may be delineated to five or six levels of detail, with the contractor responsible for developing the lower levels. A partial project WBS, to five levels of detail, is shown in Figure 9-3.

Other specialized WBSs are used that suit particular applications during design and development. For example, a product WBS could be derived from the CWBS for use in TPM analysis, to select items for performance monitoring. It would contain only those WBS elements associated with the physical system. WBS elements such as data and services would not be included in the breakdown. Needs unique to a particular discipline will often require development of variants of the basic WBS types. Possible derivatives may be: 1) T&E WBS, 2) Systems Engineering WBS, 3) TPM WBS, 4) Production Engineering and Planning (PEP) WBS, and 5) Industrial Modernization Incentives Program WBS. Each WBS would be formed by extracting particular types of tasks or products from an existing project WBS.

9.2 WBS PREPARATION

The PMO builds a project summary

Figure 9-3
Hypothetical Project WBS (Partial)



WBS tailored to program objectives by selecting applicable elements from the summary WBS in MIL-STD-881A [2]. This is usually developed at the beginning of the Concept Exploration/ Definition (C/E) phase and is included in the C/E request for proposals (RFP). From the project summary WBS, individual CWBSs are then developed by the contractor(s) in compliance with the government's instructions contained in the RFP (a preliminary CWBS is normally part of the contractor's proposal). The RFP contract line items (CLINs), configuration items (CIs), contract work statement tasks, and contract specifications, are elements of the preliminary CWBS. During C/E contract negotiations, the PMO or contractors may propose further changes to the preliminary CWBS to enhance its effectiveness in satisfying the objectives of the particular acquisition. The final CWBS will be incorporated in the C/E contract. The contractor then normally extends the detail of the CWBS in order to facilitate in-house planning and control required in each acquisition phase. Systems engineering plays the key role in the expansion of the product elements through the functional analysis, design synthesis, and trade-offs conducted to achieve the "best" break-out of product elements. The CWBS serves as the framework for the contractor's design work management system to provide summaries of internal data that are auditable and traceable.

The initial project summary WBS and first CWBS are established at the award of the first C/E contract(s). When competition

is maintained with competing alternative designs, there may be more than one project summary WBS, and there will be more than one set of contract WBSs for a program. As the program develops and additional contracts are awarded, the project WBS extends the levels it addresses, but the top level structure remains unchanged, barring major changes in system concepts.

Level commonality between the project summary WBS and the individual CWBS need not be maintained, provided that the approved project summary WBS element nomenclature and definitions are not violated. Traceable summarization of individual CWBS(s) into the approved project summary WBS ***must***, however, be maintained. The PMO incorporates into the project WBS those levels of the extended CWBS(s) that it considers necessary for program management and other related requirements. The formal project WBS is completed prior to the initiation of production.

The systems engineering process ensures that as the lower levels of the product elements of the WBS are developed, they continue to satisfy the operational needs specified in the system specification (Type A specification). The systems engineering process also ensures that any changes to the portions of the WBS under contractor control are conducted using trade-off processes and criteria that maintain system integrity. The only differences between the specification tree, which graphically represents the family of specifications for a program, and the WBS should be primarily in the level of detail, not in the correlation among product elements. Traceability should be paramount throughout the WBS framework.

9.3 WORK PACKAGING

In expanding the WBS to successively lower levels, the requirements for day-to-day task management are balanced against the performance reporting required by program management, corporate management, and the government. For example, government cost reporting generally requires very high level reporting, while contractor program management will often require more detail, or data structures that reflect internal organizational structures. The "best" WBS for the government is often not viewed as the "best" from the contractor's perspective. The requirements for this balancing are inherent in the approved capabilities/ configuration of the contractor's cost/ schedule control system. The lowest WBS elements coincide with the most efficient and cost-effective way of controlling technical performance, schedule, and cost of the program.

WBS elements should be selected to permit structuring budgets, and identification/ tracking of costs to the level required for control. This is accomplished by assigning job orders or customer orders to the cost-account level for in-house effort, and by structuring line items or work assignments on contracts in accordance with the WBS. Ordinarily, a "cost account" will be established at the lowest level in the CWBS at which costs are recorded and can be compared with budgeted costs. This cost account (WBS element) is a natural control point for cost/schedule planning and control of a single organizational element.

Contractors maintain records to the work package level. The government normally has access to costs at the cost account level.

At the lowest level, the effort is broken into discrete work packages associated with both an organization and a budgeted (cost/schedule) task as illustrated in Figure 9-4. Criteria for establishing an effective work package include the following:

a. Represent a specific, definable unit of work

b. Define a unit of work at the level where work is performed

c. Relate a unit of work directly to and as an extension of a specific element of WBS

d. Clearly distinguish the work from

that defined by other work packages

e. Assign a unit of work to a specific single organizational element

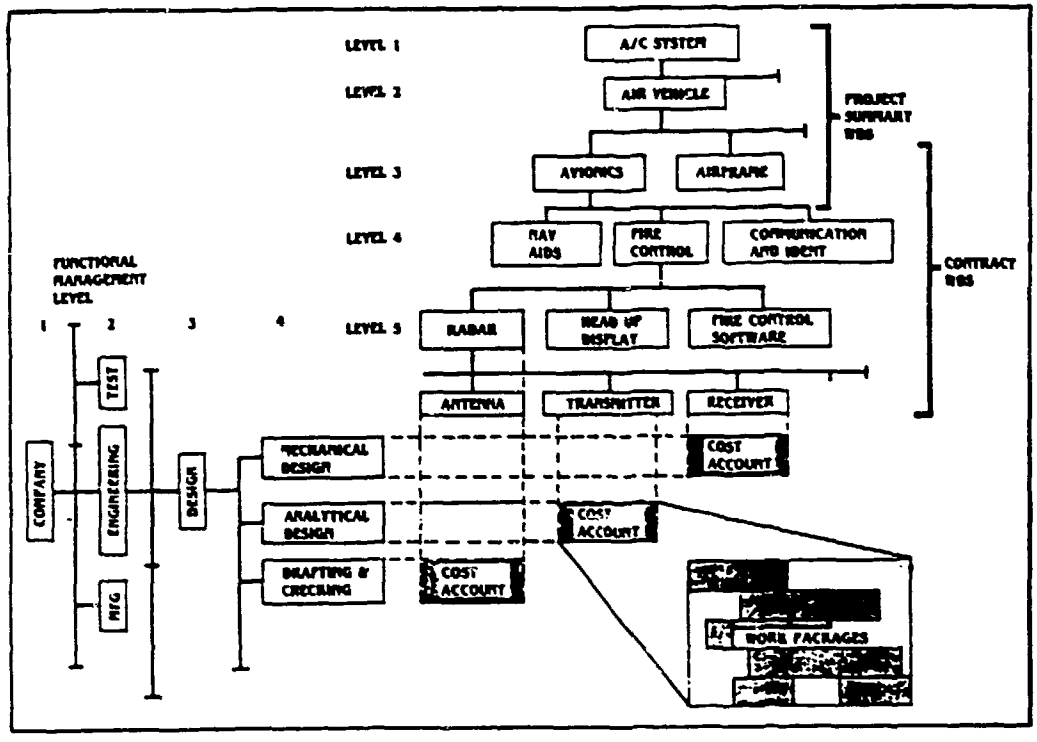
f. Identify a specific start-to-completion schedule representative of task accomplishment capability

g. Relate work package schedules directly to and as an extension of the detailed program schedule

h. Identify realistic budgetary/resource requirements

i. Limit each unit of work to a relatively short span of time

Figure 9-4
WBS/Functional Integration



j. Identify specific accomplishments (outputs) to result from a unit of work (e.g.; reports, hardware deliveries, and tests).

Support tasks associated with a particular hardware element, such as qualification tests, acceptance tests, and systems engineering, are included as part of the effort associated with that hardware element. Support tasks pertaining to the overall system effort (rather than individual hardware elements comprising the prime mission equipment) are shown at level 2 of the WBS. For example, qualification testing for a fire control radar, shown in Figure 9-3, would be included under the WBS element for the radar (1320.02) at level 5; however, operational test and evaluation (OT&E) involving the entire air vehicle is included under the WBS element for system testing (2000) at level 2.

The contractor assigns internal charge numbers for each work package identified in the CWBS, providing the detailed data source used for integrated cost, schedule, and performance reporting. Cost accounts are correlated with demonstrable performance objectives. At scheduled completion, task performance is compared with initial task objectives. If technical requirements are satisfied, the milestone completion is approved and the budget value is credited to the cost account as earned value. WBS elements not achieving required performance levels are identified through various management techniques including TPM, risk analysis, and critical path analysis. Corrective actions are developed by management to bring projected deficient performance within acceptable levels.

9.4 DOCUMENTATION

CWBS inputs are described in an expanded narrative in the CWBS dictionary. Each block or element on the CWBS diagram is identified in the CWBS dictionary. Figure 9-5 is an example of a typical WBS dictionary. Generally, the elements are assigned numbers, listed sequentially in the dictionary with necessary identification, definition, objective of the element, synopsis of the effort required, and the element's relationship to other elements. The WBS element **"Air Vehicle"**, depicted in Figure 9-5, is identified by WBS number at WBS level 2. In this example, the WBS dictionary also includes a description defining 1) what constitutes the Air Vehicle (e.g.; structural airframe, installed engines), 2) the objective (provide flyaway FXX), 3) the documents which describe the required effort (detailed specifications), and 4) the Air Vehicle's associated lower level (level 3) elements (e.g.; airframe, propulsion).

The dictionary ensures that the tasks estimated are those contained in the proposed CWBS. The proposed CWBS and dictionary should be sufficient for contractor organizations to estimate costs and schedules associated with accomplishing their assigned program tasks.

Initial development of the CWBS dictionary is normally conducted by the contractor as part of the proposal development effort for the first development contract. Maintenance, update, and resupply of the CWBS dictionary is first specified as a contractor-assigned task by the government in a contract data requirements list (CDRL)

Figure 9-5
WBS Dictionary Format

PROJECT/PROGRAM FXX	CONTRACT WORK BREAKDOWN STRUCTURE DICTIONARY	DATE	
CONTRACT NO.		SHEET 1	OF 1

WBS LEVEL						ELEMENT TITLE
1	2	3	4	5	6	
	X 1000					AIR VEHICLE

ELEMENT DESCRIPTION

AIR VEHICLE

The complete flyaway FXX for delivery to the U.S. Government. The flyaway FXX constitutes the structural airframe, installed engines and subsystems, including mission peculiar equipments, as defined by the Detail Specification for Model F-XX Aircraft Weapon System including all attendant addendums and the Avionic Specification.

WBS LEVEL						ASSOCIATED LOWER LEVEL ELEMENTS
1	2	3	4	5	6	TITLE
		X 1100				AIRFRAME
		1200				PROPULSION
		1300				AVIONICS SUBSYSTEM
		1400				FLIGHT CONTROL SYSTEM
		1500				INTEGRATION AND ASSEMBLY

accompanying that request for proposals. Maintenance and update requirements are also included on all subsequent requests for proposals.

9.5 REFERENCES

1. DoDD 5010.20, "Work Breakdown Structures for Defense Materiel Items".

2. MIL-STD-881A, "Work Breakdown Structures for Defense Materiel Items".

CHAPTER 10

STANDARDS/ SPECIFICATIONS

10.1 INTRODUCTION

The basic critical output of the systems engineering process is a complete set of system technical requirements, documented broadly in a system functional specification (Type A). This document and expanded lower-level documents promote ease of understanding of the process of design, test, production, and support of a proposed technical solution to an approved operational requirement. Every acquisition program has a set of unique specifications that define its specific technical requirements. These documents incorporate or refer to many government standards to define items, approaches, or procedures which may be used in the development and production process. These government standards are employed to give new programs the benefit of previous technical experience, to promote interchangeability and commonality, and to minimize costs of ownership. Implementation must be carefully considered to ensure that general standards/ specifications represent current technology, yet do not create unnecessary costs for the program.

10.2. SPECIFICATIONS

Specifications are documents prepared to support acquisitions and to describe items which vary greatly in complexity. Specifications form the skeleton around which the defense acquisition process is built, and are necessary to satisfy the primary objective of any procurement action, which is to obtain required products in the proper quantity, of suitable quality, in the time needed, and at the lowest possible price. [1] They will establish requirements in terms of both design details and performance. There are two basic categories of specifications: general specifications and program peculiar specifications.

10.2.1 General Specifications

General specifications, referred to as military specifications, are controlled by the Defense Standardization and Specification Program (DSSP) and apply to all acquisition programs. They are written to cover systems, subsystems, components, items, materials, products, or processes that are intrinsically military in character. General specifications represent a particular requirement at a particular time which can be used over and over again on many different acquisition programs. These specifications include 1) specifications for materials, parts, and processes, 2) test criteria documentation, and 3) management specifications.

10.2.2 Program Peculiar Specifications

Program peculiar specifications apply only to those products developed to meet specific operational requirements. The basic forms and types of program peculiar specifications

are defined in MIL-STD-490A [2] as illustrated in Figure 10-1. There are five types of program peculiar specifications: 1) system/segment specification, 2) development specification, 3) product specification, 4) process specification, and 5) material specification.

10.2.2.1 System/Segment Specification

A system/ segment specification states the technical and mission performance requirements for a system as an entity, allocates requirements to functional areas, documents design constraints, and defines the interfaces between or among the functional areas. Normally, the initial version of a system/ segment specification is based on parameters developed during the Concept Exploration/ Definition (C/E) phase. System specifications are also referred to as "Type A" specifications.

10.2.2.2 Development Specification

Development specifications state the requirements for the design or engineering development of a product. The development specification, as defined in MIL-STD-490A [2], is a document applicable to an item below the system level which states performance, interface, and other technical requirements in sufficient detail to permit its design, engineering for service use, and evaluation. Each development specification shall be in sufficient detail to describe effectively the performance characteristics that each configuration item is to achieve. Development specifications are also known as "Type B," "Part I" of two part specifications, or "design-to" specifications.

10.2.2.3 Product Specification

Product specifications are applicable to any item below the system level, and may be oriented toward procurement of a product through specification of primarily functional (performance) requirements or primarily production (detailed design) requirements. A product specification contains: 1) the complete performance requirements of the product for its intended use, 2) necessary interface and interchangeability characteristics (form, fit, and function), 3) a detailed description of the parts and assemblies of the product, and 4) those performance requirements and corresponding tests and inspections necessary to ensure proper fabrication, adjustment, and assembly. Product specifications are also referred to as "Type C," "Part II" of two part specifications, or "build-to" specifications.

10.2.2.4 Process Specification

Process specifications are applicable to a service which is performed on a product or material. Examples of processes are heat treatment, welding, plating, packing, microfilming, and marking. Process specifications cover manufacturing techniques which require a specific or unique procedure to achieve a satisfactory result. Where specific or unique processes are essential to fabrication or procurement of a product or material, a process specification is the means of defining such specific processes. Normally, a process specification applies to production, but may be prepared to control the development of a process. Process specifications are also known as "Type D" specifications.

Figure 10-1
Basic Forms and Types of
Program Peculiar Specifications

Specification Forms

- **Form 1:** Prepared According to MIL-STD-490A or its Equivalent
  - **Form 1a:** Format exactly as specified in the appropriate appendix to MIL-STD-490A
  - **Form 1b:** Limited Format Revisions
- **Form 2:** Commercial Practice Specification With Supplementary Military Requirements
- **Form 3:** Commercial Specification not Intended for Competitive Procurement

Specification Types

- **Type A:** System/Segment Specification
- **Type B:** Development Specification
  - **Type B1:** Prime Item
  - **Type B2:** Critical Item
  - **Type B3:** Non-Complex Item
  - **Type B4:** Facility or Ship
  - **Type B5:** Software
- **Type C:** Product Specification
  - **Type C1b:** Prime Item Function
  - **Type C1b:** Prime Item Fabrication
  - **Type C2a:** Critical Item Function
  - **Type C2b:** Critical Item Fabrication
  - **Type C3:** Non-Complex Item Fabrication
  - **Type C4:** Inventory Item
  - **Type C5:** Software
- **Type D:** Process Specification
- **Type E:** Material Specification

10.2.2.5 Material Specification

Material specifications are applicable to raw materials (chemical compound), mixtures (cleaning agents, paints), or semi-fabricated materials (electrical cable, copper tubing) used in the fabrication of a product. Normally, a material specification applies to production but may be prepared to control the development of a material. Material specifications are also known as "Type E" specifications.

10.3 MILITARY AND DOD STANDARDS

Military and Department of Defense (DoD) standards are documents that establish engineering and technical requirements for processes, procedures, practices, and methods that have been adopted as standard. They are created primarily to serve the needs of designers. Their purpose is to control variability of products and processes.. They include materials, items, engineering practices, processes, codes, symbols, type designations, definitions, nomenclature, test, inspection, packaging and preservation methods and materials, and other standardization topics. The distinction between military and DoD standards is that DoD standards are approved for use with the metric system of measurement.

10.4 HANDBOOKS

A handbook is a reference document which brings together procedural and technical or design information related to commodities, processes, practices, and services. A handbook may serve as a supplement to specifications or standards to provide general design and engineering data.

10.5 DRAWINGS

Drawings are referenced in many standardization documents and supply management records. Conversely, specifications and standards are often referenced in drawings to identify the materials, processes, and standard items incorporated in assemblies and equipment. The basic standardization documents for drawings are DOD-D-1000B [3] which prescibes the requirements for engineering drawings and lists acquired in support of DoD material, and DOD-STD-100C [4] which provides 1) drawing practices for the preparation of engineering drawings, 2) procedures for numbering, coding and identification of drawings, 3) methods for revising and recording revisions on drawings, and 4) requirements for the preparation of associated lists.

There are three levels of engineering drawings. Level 1 drawings are used primarily in the design effort to ensure that the proposed design meets the stated operational requirements. These drawings are used to reduce technological uncertainties by confirming that the chosen technology is feasible and suitable for analytical evaluation. Level 1 drawings verify the preliminary design and serve as the basis for a specific design approach. Level 2 drawings serve as the basis for the final design approach. These drawings ensure that the operational requirements are met with respect to performance and standard parts. They can be used for limited production of items which are suitable for field test, deployment and logistic support. Level 3 drawings are similar

Figure 10-2
Specification Summary

SPECIFICATION	WHEN PREPARED	PREPARING AGENT	APPROVING AGENT	CONTENT	BASE-LINE
SYSTEM/SEGMENT (TYPE A)	CE PHASE	DEV/PROG MGR INDUSTRY	DEV/PROG MGR USER	DEFINE MISSION AND TECH REQMTS; ALLOCATES REQUIREMENTS TO FUNCTIONAL AREAS; DOCUMENTS DESIGN CONSTRAINTS; DEFINES INTERFACES	FUNC-TIONAL
DEVELOPMENT (TYPE B, PART I, DESIGN-TO)	LATE D/V PHASE	INDUSTRY	DEV/PROG MGR	DETAILS DESIGN REQUIREMENTS; STATES DESCRIBES PERFORMANCE CHARACTERISTICS OF EACH CI; DIFFERENTIATES REQUIREMENTS ACCORDING TO COMPLEXITY AND DISCIPLINE SETS	ALLO-CATED
PRODUCT (TYPE C, PART II, BUILD-TO)	LATE FSD PHASE	INDUSTRY	DEV/PROG MGR	DEFINES FORM, FIT, FUNCTION, PERFORMANCE, AND TEST REQUIREMENTS FOR ACCEPTANCE	PRODUCT
PROCESS (TYPE D)	FSD/PROD PHASES	INDUSTRY	DEV/PROG MGR	DEFINES PROCESS PERFORMED DURING FABRICATION	
MATERIAL (TYPE E)	FSD/PROD PHASES	INDUSTRY	DEV/PROG MGR	DEFINES PRODUCTION OF RAW OR SEMI-FABRICATED MATERIAL USED IN FABRICATION	

to level 2 drawings, but are more detailed in certain areas to allow for a competitive reprocurement from another manufacturer. They provide the engineering data in support of quantity production.

10.6 PROGRAM SPECIFICATION DEVELOPMENT PROCESS

Program peculiar specifications, as products of the systems engineering process, play an integral role in the product development process. This relationship is shown in Figure 10-2.

Specifications established during the system acquisition process differ for each type of activity. They should state only the actual minimum needs of the government, and should describe supplies and services in a manner that encourages competition among qualified suppliers. They should also avoid restrictive requirements that might inhibit submittal of acceptable alternative proposals.

During the C/E phase, a draft system specification (Type A) is prepared to establish the system functional baseline defining mission and technical requirements. The draft system specification for the initial solicitation of system concepts may be little more than a copy of the operational requirement; e.g., Mission Need Statement (MNS). Additional material provided in the solicitation for system design concepts should avoid specifications stated in terms of equipment; rather, it should explain the need in mission or capability terms, schedule objectives and constraints, project cost objectives, and operational constraints. By the end of the C/E phase, each contractor should have prepared and submitted a refined system specification stating the technical and mission requirements of the system as an entity and allocating requirements to functional areas. The system specification should be devoid of all details that could later inhibit the construction of critical subsystems, equipment, and components, or the demonstration of the concept's technological feasibility. The completed Type A specification, shown in Figure 10-3, will be approved by the Program Manager (PM) in conjunction with the System Design Review (SDR). Once approved, the system specification establishes the functional baseline configuration for the proposed system.

During the Concept Demonstration/ Validation (D/V) phase, draft development specifications (Type B) are developed to establish an allocated baseline for each designated configuration item (CI). These specifications contain detailed design requirements and performance characteristics of each hardware and computer software configuration item (HWCI and CSCI respectively). The development specifications should reflect traceability of requirements to the system specification. Once the system specification is approved, the development specifications can be updated accordingly to reflect the current definition of the system and the allocation of system requirements to their specific functional areas. The draft development specifications are updated and authenticated early in the Full Scale Development (FSD) phase, usually not later than the Critical Design Review (CDR). For hardware, this normally occurs in conjunction with the HWCI Preliminary Design Review (PDR); for software, this normally occurs in conjunction with the Software Specification

Figure 10-3
System/ Segment Specification Outline

Section	1	SCOPE
Section	2	APPLICABLE DOCUMENTS
Section	3	REQUIREMENTS
Paragraph	3.1	System Definition
	3.1.1	Missions
	3.1.2	Threat
	3.1.3	System Modes and States
	3.1.4	System Functions
	3.1.5	System Functional Relationships
	3.1.6	Configuration Allocation
	3.1.7	Interface Requirements
	3.1.8	Government Furnished Property List
Paragraph	3.2	System Characteristics
	3.2.1	Physical Requirements
	3.2.2	Environmental Conditions
	3.2.3	Nuclear Control Requirements
	3.2.4	Materials, Processes, and Parts
	3.2.5	Electromagnetic Radiation
	3.2.6	Workmanship
	3.2.7	Interchangeability
	3.2.8	Safety
	3.2.9	Human Performance/Human Engineering
	3.2.10	Deployment Requirements
	3.2.11	System Effectiveness Models
Paragraph	3.3	Processing Resources
Paragraph	3.4	Quality Factors
	3.4.1	Reliability
	3.4.2	Modifiability
	3.4.3	Availability
	3.4.4	Portability
	3.4.5	Additional Quality Factors
Paragraph	3.5	Logistics
	3.5.1	Support Concept
	3.5.2	Support Facilities
	3.5.3	Supply
	3.5.4	Personnel
	3.5.5	Training
Paragraph	3.6	Precedence
Section	4	QUALIFICATION REQUIREMENTS
Paragraph	4.1	General
	4.1.1	Philosophy of Testing
	4.1.2	Location of Testing
	4.1.3	Responsibility for Tests
	4.1.4	Qualification Methods
	4.1.5	Test Levels
Paragraph	4.2	Formal Tests
Paragraph	4.3	Formal Test Constraints
Paragraph	4.4	Qualification Cross Reference
Section	5	PREPARATION FOR DELIVERY
Section	6	NOTES
APPENDIXES		

Review (SSR). The updated system specification and the series of development specifications constitute the system allocated baseline configuration which will constrain contractor efforts during FSD. The specifications should not contain details that would inhibit the important trade-off studies and design evolution process vital to this phase.

By the time of CDR, the contractor(s) should have provided a final update of the development specifications and a series of draft product specifications (Type C). The product specifications should provide the detail necessary to permit economical procurement of functional elements that, when assembled into a system, will perform as a system in accordance with the current system specification. Product specifications are normally approved in conjunction with the Physical Configuration Audit (PCA) conducted on each CI; thereby establishing the product baseline for each CI. The technical data package (TDP) represents the formally accepted drawings and specifications required to produce, test, and accept the various configuration items. This package constitutes the product baseline configuration of the system and will be contractually invoked for any procurement/ reprocurement of the system.

10.7 SPECIFICATION TERMINOLOGY

A specification is a series of requirement statements written in clear, simple language. It should not contain descriptive matter or vague, redundant, or ambiguous statements. Nebulous adjectives or modifiers such as "adequate," "excessive," or "moisture resistant," should be avoided. The strictest requirement statements employ the word "shall," indicating the need for absolute compliance with the requirement. The following phrases may be employed alternately (in descending order of compliance):

a. "Shall, where practical" (trade-off analysis required if alternate used)

b. "Preferred" or "should" (use of alternate must be justified)

c. "May" (contractor's selection acceptable).

Use of these terms allows the contractor additional latitude to propose a cost-effective solution. The use of "will" is limited to cases of simple futurity, such as a declaration by the government that some item or service will be available for use when needed. The term "and/or" shall not be used in specifications. Specifications shall not include management, procedural, or statement of work (SOW) items such as quantities, schedules, costs, warranty provisions, or disposal instructions. Requirements should be quantified and verifiable. The need to use judgment in verification, such as "best design practice," "smooth," "good workmanship," "clean," or "minimum bend radius," shall be avoided as much as possible.

10.8 ACQUISITION STREAMLINING/ TAILORING

Acquisition streamlining is the reduction of acquisition time and cost by eliminating unproductive government requirements from solicitations and contracts. Streamlining calls for using the creativity of those closest to the

detailed design and manufacturing process in defining the most cost-effective contract requirements at the most opportune time. The DoD acquisition streamlining initiative also calls for practical measures to preclude untimely, untailored, and accidentally referenced application of military specifications and standards; that is, to specify required results rather than detailed "how to" procedures in solicitations and contracts. The objective of streamlining is to clearly communicate what is required in functional performance oriented terms at the beginning of development and to allow flexibility for the application of the contractor's experience and judgment. The contractor is required by contract to recommend detailed specifications, standards, and requirements which should be applied as the weapon system evolves toward FSD and eventually production. In this way, the application and tailoring of specifications and standards become an integral part of the design process.

There are more than 40,000 military specifications and standards in the DSSP. The average age of these military specifications is more than 11 years. Cost-effective application of the pertinent portions of these documents to a system acquisition program should be an integral part of the design and development process. Too frequently, however, these documents are invoked in boiler plate, blanket fashion early in the program, so that they prematurely constrain contractor systems engineering activities. Documents are also invoked implicitly by reference in the primary document (automatic tiering). For example, Document A specified by contract may invoke Documents B, C, and D by reference, and they in turn will invoke Documents E, F, G, and H. Premature constraint of contractor activities inhibits trade-offs that may be necessary to achieve overall systems engineering objectives such as affordability, producibility, reliability, and supportability. Both over-use of military specifications and automatic tiering may contribute to suboptimum designs and unnecessary escalation of acquisition costs. A number of factors have contributed to this problem on the parts of both the government and the contractor:

a. Over-conservative approach to design engineering

b. Failure to challenge requirements during design and development

c. Follow-on production using the original system TDP which was adequate at the time, but may no longer be cost-effective due to new technology and revised operational requirements

d. Lack of adequate technical data to assess over-specification.

The traditional approach to tailoring specifications and standards does not take into consideration the timing of the tailoring task. The application and tailoring of military specifications and standards is basically a development and design issue. Selection and tailoring of military specifications and standards should be a product of the systems engineering process rather than an element of production contract definition. During C/E and D/V, the contractor has the systems engineering manpower base to effectively handle the

labor-intensive task of tailoring.

The traditional problems which occur when tailoring is done exclusively by the government include:

a. Insufficient time during RFP preparation

b. Insufficient manpower, skills, and information

c. Functional organization bias and inclination to specify design solutions

d. Desire to minimize risks by maximizing requirements

e. Lack of contractor incentives to assist or question the program office tailoring decisions

f. If the contractor's proposal includes changes to the use or content of military specifications and standards, contractor concern that it will be perceived as non-responsive, or that it will disclose information that could compromise its competitive position.

Imposing unnecessary or untailored requirements contractually may lead to poor discipline regarding compliance with contract requirements in general. As a result, compliance with truly necessary requirements may be ignored by either the program office or the design contractor. Effective streamlining, on the other hand, leads to the development of fewer and more effectively defined contract requirements which in turn may foster disciplined adherence to all contract requirements. In addition, acquisition streamlining seeks to cut down on government requirements for data (by limiting data requirements to those actively determined to be necessary for technical management purposes). Chapter 14 of this guide describes the methodology for selecting "essential documentation" in lieu of "everything possible."

An acquisition streamlining approach has been outlined in DoDD 5000.43 [5]. It is intended to:

a. Utilize contractor ingenuity and experience in arriving at cost-effective designs, while retaining government PM decision-making authority

b. Support the basic requirement to pursue, throughout the system development process, a design that is economically producible as well as operationally suitable and field-supportable

c. Ensure development of complete and definitive production data and specifications, while providing adequate flexibility to the contractor to optimize the system design.

DoD guidance on streamlining, including DoDD 5000.43 [5] and DoD-HDBK-248 [6], has been developed to facilitate implementation. The following are procedures regarding contractual referencing aspects of the streamlining initiatives [7]:

a. At Milestone 0, specify system-level requirements in mission performance terms. Prior to FSD, military specifications and standards shall be cited for guidance only. These documents shall be evaluated and, if

required, tailored for application to FSD.

b. For FSD contracts, limit contractual applicability of specifications, standards, and related documents to those cited in the contract, and to specified portions of documents directly referenced by those cited (first-tier references). All other referenced documents (second-tier and below) shall be for guidance only, unless specifically called out in the contract.

c. For production contracts, those specifications, standards, and referenced documents comprising the baseline for production shall be considered contractual requirements for procurement and reprocurement purposes. Acquisition streamlining should continue throughout the production phase, with emphasis on ensuring that only essential production and data requirements are carried forward into follow-on production contracts.

d. When there is a decision to use items already developed, such as standard parts and off-the-shelf items, all specifications and standards that define the product baseline for the items are contractually applicable, irrespective of the acquisition phase.

Previously, recommendations for tailoring of specifications/ contract requirements by the contractor were optional. However, DoDD 5000.43 [5] now stipulates that contractors be required, under the terms of the contract for a particular phase, to propose recomendations for application and tailoring of specifications/ contract requirements in the next phase. This activity must become an integral part of systems engineering plans. As system design evolves through D/V, lower-tier specifications and standards will normally be selected and tailored for the next phase. For example, identified requirements should be reviewed by systems engineering, tailored as appropriate, and identified as requirements in the FSD proposal. During FSD, a primary task should be to review and scrub lower-tier references to ensure that manufacturing and process standards are cost-effective. Normally this process would be completed by CDR. The government PM will make the final determination as to which contract requirements should apply to the production phase. The checklist shown in Figure 10-4 can be used by the PM in reviewing data requirements statements, specifications, and standards for incorporation in contracts.

The directive [5] further specifies the use of the contractor's management systems, internal procedures, data formats, etc., unless the program office determines that these do not meet program needs. This increased emphasis on contractor systems, procedures, and documents increases the contractor's flexibility in generating program documentation in the most efficient and effective manner. Use of contractor management systems will be effective only if each program office anticipates the requirement for timely, careful review of proposed procedures and formats.

10.8.1 Application and Tailoring of General Procurement Standards

Procedures and policy for the Defense Standardization and Specification Program (DSSP) are promulgated by DoDD 4120.3 [8]. Specifications, standards, handbooks, and other engineering documentation

prepared under the DSSP are intended to state only the actual needs of the government in a manner that will encourage maximum competition. The objectives of the DSSP (defined by DoD 4120.3-M [9]) are to accomplish the following:

a. Improve the operational readiness of the military services

b. Conserve money, manpower, time, facilities, and natural resources

c. Optimize the variety and minimize variability of items (including subsystems), processes, and practices used in acquisition and logistic support

d. Enhance interchangeability, reliability, and maintainability of military equipment and supplies

e. Ensure that products of requisite quality and minimum essential need are specified and obtained

f. Ensure that specifications and standards are written to facilitate tailoring of prescribed requirements to the particular need

g. Ensure that specifications and standards imposed in acquisition programs are tailored to reflect only particular needs consistent with mission requirements.

The application of general military/ DoD specifications and standards to program unique requirements is an essential element in transferring the accumulated knowledge of the military environment to new programs. It can greatly reduce the repetition of development efforts and tests that are fully provided in the referenced standards. Great care must be exercised, however, to ensure that the standards are properly applied to suit the stage of program maturity and that these requirements are adequate and pertinent to the needs of the program.

In addition to the specific program office review of standards as part of the acquisition streamlining program described in the previous section, DoD has also established procedures for continued review and revision of standardization documents, including a mandatory review of all documents that have not been amended, revised, or validated for a period of five years. However, update may involve intervals considerably longer than five years. Both government and industry are responsible for ensuring that each procurement standard imposed during development is both suitably tailored and current.

There are a number of appropriate ways to tailor procurement standards. The application of a standard may be limited to specified components or types of components (for example, airborne electronics) within the system by specifying the limits in the body of the system specification. Applicable portions of a standard may also be extracted for incorporation into the text of a development specification. In either case, a referenced standard may be supplemented by descriptive text in the specification which clarifies the intended requirements or application. Inapplicable portions of the standard may be deleted by identifying them in an appendix to either specification.

In the application and tailoring of standards, the order of precedence is (highest

to lowest):

a. Specifications (federal, military, program peculiar)

b. Standards (federal, military, industry)

c. Handbooks (governmental).

10.9 RISK TEMPLATE: DATA REQUIREMENTS

Procurement of excessive technical data increases the risk of cost overruns. Use of data procured by different government functional organizations without program office coordination often results in redundant requirements on the contractor. It is estimated that direct costs for data range from 6 to 20 percent of contract value, not including the overhead costs and the cost to the government to process, review, and manage the data.

A corollary problem is failure to effectively use data for program control. Control of data requirements, in the past, has been sporadic. Even though the problem of poor data management has been identified in various studies over the past 20 years, it receives little emphasis where there is a lack of top level commitment. DoD 4245.7-M **[10]** makes the following recommendations for reducing program risk:

a. All procurement data requirements should be reviewed by an effective data review board before contract award to ensure that the data received will satisfy the government's needs, is in a format suitable for customer use, and is not redundant.

b. An integrated data management system should be established, both in government and industry, for each major procurement. The objective of this system is to tailor the technical data requirements to the needs of each program.

c. Electronic data transfer should be used to allow access to pertinent data required by the government. The requested data can then be exercised in the government's data base to extract the required information.

d. The data requirements for a major program should be reviewed at a level high enough to ensure that redundant data are not being requested by the different disciplines within the program office and its functional support organizations.

e. Technical data libraries should be established for ease of data retrieval, and the data should be kept current.

f. Data requirements should be reviewed during each phase of the program to ensure that data being procured meet the needs of that particular program phase.

g. Data should be procured using well-defined data requirements lists, reasonable cost estimates, and realistic schedules.

10.10 REFERENCES

1. Report to SECDEF by USD(A), "Enhancing Defense Standardization-Specifications and Standards: Cornerstones of Quality", November 1988

2. MIL-STD-490A, "Specification Practices".

3. DoD-D-1000B, "Drawings, Engineering, and Associated Lists".

4. DoD-STD-100C, "Engineering Drawing Practices".

5. DoDD 5000.43, "Acquisition Streamlining".

6. DoD-HDBK-248, "Guidance for Application and Tailoring of Requirements for Defense Materiel Acquisitions".

7. DEPSECDEF Memorandum of June 3, 1985; "Acquisition Streamlining".

8. DoDD 4120.3, "Defense Standardization and Specification Program".

9. DoD 4120.3-M, "Defense Standardization Manual".

10. DoD 4245.7-M, "Transition fro: Development to Production".

CHAPTER 11

CONFIGURATION MANAGEMENT

11.1 INTRODUCTION

Configuration management (CM) is an integral part of the systems engineering management process for system definition and control. Its role is 1) to identify the functional and physical characteristics of selected system components, designated as configuration items (CIs), during the system's acquisition life cycle; 2) to control changes to those characteristics; and 3) to record/ report change processing and implementation status. CM is thus the means through which the integrity and continuity of the design, engineering, and cost trade-off decisions made between technical performance, producibility, operability, testability, and supportability are recorded, communicated, and controlled by program and functional managers [1]. One of the rewards of an effective CM process is improved supportability, including updated technical manuals/ documentation, identified spares, identical/ interchangeable equipment, and known configuration.

At any given time, CM can supply current descriptions of developing hardware configuration items (HWCI), computer software configuration items (CSCI), and the system itself. CM provides traceability to previous baseline configurations of the system and for each of the CIs. CM also contains complete information on the rationale for configuration changes, thus permitting analysis and correction of deficiencies when they arise. CM involves four distinct functions : 1) Configuration Identification; 2) Configuration Control; 3) Configuration Status Accounting; and 4) Configuration Audits [2].

CM can be initiated by inputs from the systems engineering process as early as the Concept Exploration/ Definition (C/E) phase and continues throughout the acquisition life cycle as the system develops and is modified. Configuration changes occur throughout the life of the system as 1) more knowledge of the system design, operation, and maintenance concepts is gained; 2) mission requirements change; or 3) non-technical factors such as cost and schedule influence the design. These changes must be controlled to ensure first that they are cost-effective, and second that they are properly documented so that all users are aware of the current configuration status.

11.2 ESTABLISHING THE BASELINE CONFIGURATION

One of the more important aspects of CM is the concept of baseline management. Baseline management is formally required at the beginning of an acquisition program. The Joint Services Regulation on CM [3] implements DoDD 5010.19 [2] and defines the baseline configuration to which CM is to be applied.

11.2.1 Functional Baseline

The system functional baseline is established with the approval of the the system level specification (Type A specification) which defines the technical portion of the program requirements. Ideally, the system specification should be approved by the end of C/E, but normally is approved during the Concept Demonstration/ Validation (D/V) phase for major weapon system programs. An output of C/E activity is a draft system specification which may be approved by the government at that time or used as an initial system specification in the request for proposal (RFP) package for the D/V effort and approved during D/V. The system specification provides the basis for controlling the system design during the system's life cycle and once approved, formal configuration control is initiated.

11.2.2 Allocated Baseline

An allocated baseline is established for each CI with the approval of their individual development specification (Type B specification). These specifications define the particular performance requirements for each individual CI. They are normally developed during D/V and approved early in the Full Scale Development (FSD) phase. The development specifications incorporate the technical approaches developed to satisfy the objectives of the system functional baseline. These objectives are translated through the systems engineering process into subsystem and CI performance requirements. Initial development specifications for each CI are included in the RFP for the FSD effort and approved during FSD. The development specification establishes the allocated baseline for a CI and provides the basis for detailed design and development of that CI during FSD.

11.2.3 Product Baseline

The product baseline is established for each CI with the approval of their individual product specification (Type C specification), including associated process and material specifications (Types D and E specifications respectively), engineering drawings, and detailed design documentation. The product baseline establishes the requirements for HWCI fabrication and CSCI coding respectively. These CI product baselines are the basis of the production RFP and subsequent statements of work (SOW). The product baseline is verified by successful completion of the Functional Configuration Audit (FCA) and Physical Configuration Audit (PCA).

11.2.4 Configuration Control Board

During development, the government's Configuration Control Board (CCB) is responsible for reviewing and issuing changes to the configuration baseline. The CCB reviews all Class I Engineering Change Proposals (ECPs) to determine if a change is needed and to evaluate the total effect of the change. The CCB typically consists of a representative from each of the following organizations: Chairman- Program Management Office (PMO) representative, User Command(s), Engineering, Training, Logistics, Procurement/ Contracts, Configuration Management (Secretariat), Manufacturing/ Production, and others as required.

Within the contractor's organization, CM functions are normally assigned to a configuration manager. The contractor may also have its own internal CCB with responsibility for screening changes prior to government review.

11.3 CONFIGURATION MANAGEMENT PRACTICES

An excellent description of CM practices can be found in AFSCP 800-7 [4]. The following paragraphs are based on that document.

11.3.1 Configuration Identification and Status Accounting

Configuration identification is the family of specifications and drawings that describes the system or CI during the design/ development cycle. The identification becomes more precise as the design progresses toward production. This family of documents provides the basis for development, testing, production, delivery, operation and support throughout the total system life cycle. CIs are identified through allocation of the system specification requirements into lower tier requirements that subsequently become the technical performance development specifications for each CI. Division of a system into configuration items is a technical management decision. In other words, it is an acknowledgement that one item should be managed differently than another. Selection of CIs is a matter of judgment. Guidelines for CI selection are given in Appendix XVII of MIL-STD-483 [1]. Each CI should be produced by a single contractor and tested as an entity. The program office should also limit the number of CIs in order to control the management effort and reduce cost to the government.

Once the CIs are identified, the specifications defining them can be produced. The CI identification function must ensure that:

a. All technical documentation describing the functional and physical characteristics of CM items is completely defined.

b. Verified technical documents defining the baseline are current, approved, and available for use when needed.

The CI identification number provides a permanent reference number for all CIs in a given type, model, or series. Part numbers are usually needed down to the throw-away components of the lowest repairable item.

Configuration status accounting is a management information system that provides traceability of configuration identification and changes thereto, and facilitates the effective implementation of changes. It consists of reports and records documenting actions due to changes that affect the CI. The basic documentation includes the Configuration Identification Index, describing the approved configuration, and the Configuration Status Accounting Report, describing the current configuration. Standardization of data elements with regard to format, frequency, and record keeping, is defined in MIL-STD-482 [5].

11.3.2 Configuration control

Changes to CIs can only be effected by

a duly constituted CCB, as described in paragraph 11.2.4. The CCB first defines a baseline comprising the specifications which govern development of the CI design. Proposed changes to this design are classified as either Class I or Class II changes. Class I changes affect form, fit, or function. However, other factors such as cost or schedule can cause a Class I change. A non-exclusive list of potential items is provided in Figure 11-1 (see also Section 4 of DoD-STD-480 [6]). Class I changes must be approved by the Government prior to being implemented by the contractor.

All other changes are Class II changes. Examples of Class II changes are editorial changes in documentation or hardware changes (such as material substitution), which do not qualify as Class I changes. Government concurrence generally is required in order for the contractor to implement Class II changes. Government plant representatives (CAS, NAVPRO, AFPRO) usually accomplish this task.

Changes are prioritized as "emergency, urgent, or routine" as defined in DoD-STD-480 [6], according to the

Figure 11-1

Items Prompting a Class I Change

1. System Specification
2. Authenticated Specification (part I or part II)
   a. Performance requirements outside stated tolerances
   b. Reliability, maintainability, survivability
   c. Weight, balance, or moment of inertia
3. Type designator or drawing number (When operating limits/performance are extensively changed, new ones are required.)
4. Major component interface characteristics
5. Contract price
6. Contract schedule or delivery rate
7. Contract guarantees
8. Government-furnished equipment (GFE)
9. Safety
10. Electromagnetic characteristics
11. Other systems or development support systems
12. Support equipment (SE)
13. Capability of the item CI/System with support equipment, trainers or training devices/equipment
14. Delivered operation and maintenance manuals for which change/revision funding is not on existing contracts
15. Life cycle cost (development, production recurring, production nonrecurring, or operating and support cost)
16. Existing spares (obsolete or require modification, or will new spares be required)
17. Interchangeability, substitutability, or replaceability of the item to all subassemblies and parts or repairable assemblies (exclude pieces and parts of nonrepairable subassemblies)
18. Sources of assemblies repairable parts at any level that are defined by source control drawings
19. Change requires a retrofit (attrition or kit)

criticality of the change. Emergency changes should be processed within 48 hours, urgent changes within 30 calendar days and routine changes within 90 calender days. Typically a CCB meets weekly, but meetings may be convened on 24-hour notice according to need.

The configuration control process is shown in Figure 11-2 and includes both government and contractor functions. The process is initiated by: 1) Government direction; 2) Interface Control Working Group (ICWG) activity; 3) Contractor design or test definition activity; or 4) Subcontractor action.

A change package is first prepared that includes the following:

a. Statement of the problem and description of proposed change

b. Alternatives considered.

c. Analysis showing that the change will solve the problem.

d. Analysis to assure that the solution will not introduce new problems.

e. Verification of interface compatibility including test, operations, safety, and reliability.

f. Estimate of cost and schedule impact.

g. Proposed specification or Interface Control Document (ICD) revision.

h. Impact if not implemented.

After internal review by the contractor, Class I changes are prepared in either an Advance Change/ Study Notice (ACSN) (AFSC Form 223), a Preliminary Engineering Change Proposal (PECP), or an Engineering Change Request (ECR). Occasionally, the change may result in a Request for Deviation/ Waiver (DD Form 1694). Interface changes are defined on an Interface Revision Notice (IRN). Following approval of the ACSN or ECR by the government, a formal ECP (DD Form 1692) is developed containing Specification Change Notices (SCNs) (DD Form 1696) and the change pages, together with supporting cost data. Upon ECP approval by the government, the implementation plan is issued. Implementation status is monitored by both the government and contractor CM organizations.

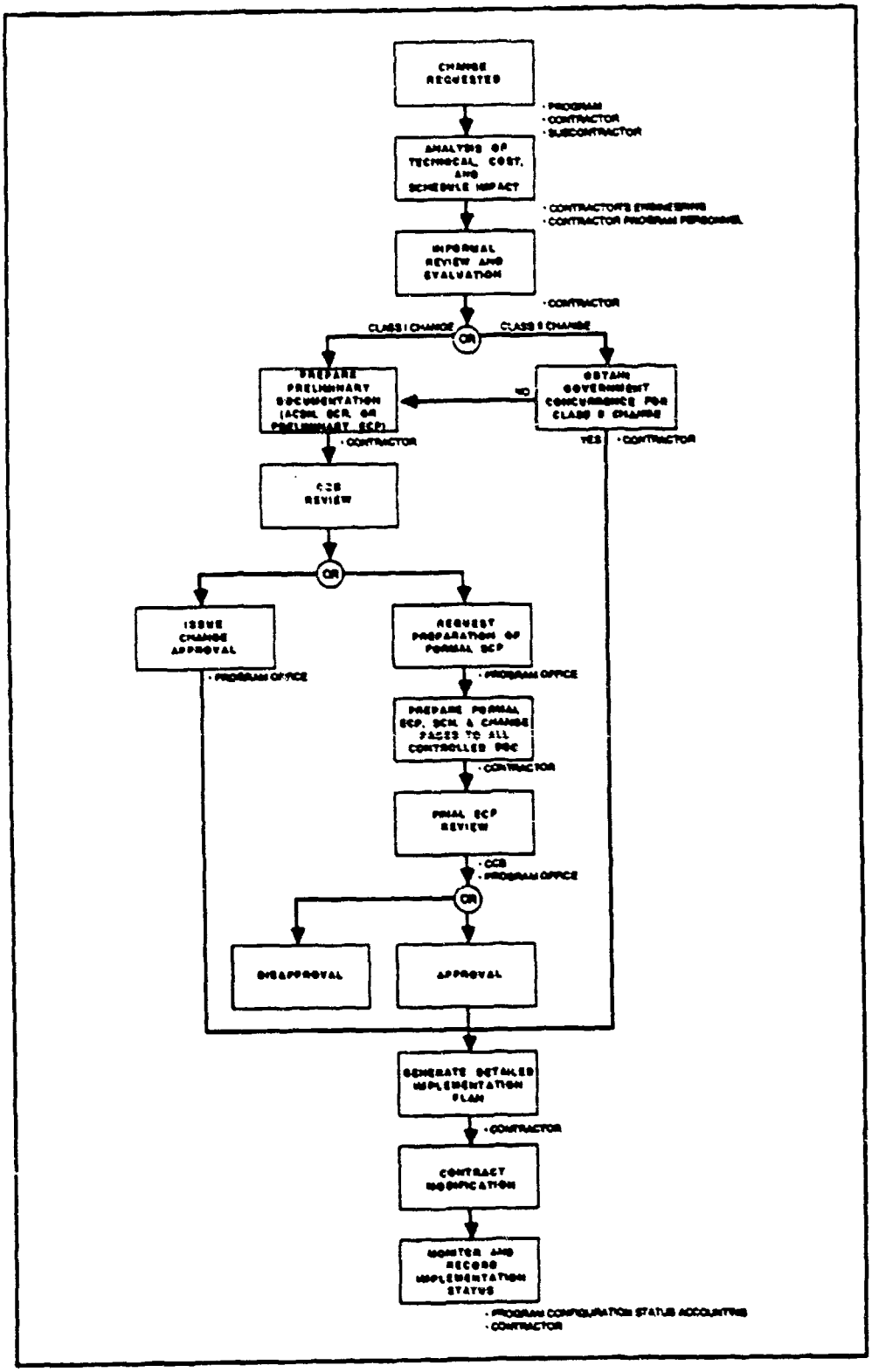
Changes to released ICDs are processed as defined for baseline changes with an additional step. Each proposed ICD change must be reviewed and approved by the ICWG prior to approval of the ECP, which allows incorporation of the change into the hardware and software. For that purpose, a Preliminary Interface Revision Notice (PIRN) approved by the ICWG will accompany the ECP. Approval of the ECP approves the PIRN.

11.3.3 Interface Management

Functional and performance interface requirements are contained in the appropriate segment or CI specifications. When functional requirements are allocated, interfaces may be incorporated in the design with full consideration for design issues.

Figure 11-2

Configuration Control Process



Systems engineering and configuration management personnel must coordinate the large number of contractors and organizations participating in the design effort to ensure compatibility of all interfaces. For this purpose, interfaces are identified and coordinated by ICWGs, which are generally organized by the prime contractor or system integrator, if the latter is a separate entity. A representative from the government PMO may chair the group, although this position is often filled by the prime contractor, with a program office co-chairman to ensure resolution of any perceived contractual conflicts that may arise between associate contractors. The ICWGs may be composed of several panels handling specialized interface areas such as electromagnetic compatibility, computer resources, and test planning. The chairman organizes these groups, ensuring that the proper specialists are supported by individuals with authority to commit their organizations or to obtain their organizations' approval for ICDs developed by the ICWG.

The nature of the ICD varies considerably, depending on the interface being documented. It can be a physical interface, a radio frequency interface, or an operational interface. Interface definition takes the forms of drawings, schematics, function lists, data format diagrams, operational procedures, equations, and other data required by the designers to completely detail their design. Electrical circuitry, for example, is usually defined to include the first active circuit on either side of the interface. The ICD does not duplicate the specification, rather it describes the design implementation of the requirements in the specification.

The ICD outline is prepared by the prime contractor, and portions are assigned to parties responsible for the agreement of the interface between system components, including human engineering factors. Systems engineering must also ensure that various interfaces are compatible or do not force unnecessary costs on interfacing systems. Following completion, the ICD is signed by all parties involved at the interface and is placed under configuration management control. The ICD then has the same status as a specification in that it represents the baseline configuration, and any changes must be acted upon by the appropriate CCB. A number of CCBs may be involved in implementing an ICD change, including CCBs of interfacing contractors or the government program office that must approve any changes to the segment interfaces.

There is no MIL-STD format for the development of ICDs similar to that of MIL-STD-490 [7] for specifications. A sample ICD outline is provided in Chapter 4 of this guide. Note that the ICD addresses not only the design implementations of an interface, but also covers items such as exchange of models (both physical and mathematical), facilities required, and availability of personnel for special integrated operations. It also identifies responsibility for verification, similar to specification practice.

11.3.4 Configuration Audits

Audits validate that development requirements are achieved and that product

configuration is identified by comparing the CI with its technical documentation. Two kinds of audits are performed: 1) Functional Configuration Audit (FCA) and 2) Physical Configuration Audit (PCA), as described in MIL-STD-1521 [8] and Chapter 12 of this guide.

The FCA is a means of validating that development of a CI has been completed satisfactorily and that the item functions as required. It is a prerequisite to the PCA. The FCA is normally performed during FSD just prior to production.

The PCA is a means of establishing the product baseline as reflected in the product configuration identification, and is used for the production and acceptance of CIs. The PCA may be accomplished during FSD; however, it is usually delayed until the beginning of the Production phase so it may be accomplished on an early representative production unit. A PCA is normally required on the first CI to be delivered by a new contractor even though a PCA was previously accomplished on a like-production article delivered by a different contractor.

11.4 DOCUMENTATION

11.4.1 Configuration Management Plan

For major systems, a Configuration Management Plan (CMP) is usually required to be submitted by the contractor either with the FSD phase proposal or early in FSD. The plan content for HWCIs is outlined in Appendix I of MIL-STD-483 [1]. The plan content for CSCIs is included in the Software Development Plan (SDP), the Software CMP, or the System CMP. Once the system is deployed, however, CM becomes the responsibility of the government. The configuration of all units, regardless of location, must be known in order to ensure that changes and modifications can be installed promptly and properly. The government's CMP must make provision for data flow to and from deployed units, to ensure current configuration knowledge. Appendix XI [1] describes the System Allocation Document, which provides the geographical location of each CI and its installed equipment. Appendix XV [1] defines the method for reporting the accomplishment of changes.

11.4.2 CCB Documentation

CCB documentation includes approved Class I ECPs with change pages for updating the baseline. In addition, the CCB will distribute minutes normally containing the agenda, a list of attendees, a summary of discussions on each item, the disposition of each agenda item with justification, change package charts, and supporting reports/analyses, as applicable.

11.4.3 Change Control Forms

Change control forms are the basic means of initiating, evaluating, approving, releasing, and implementing changes. They can also be used for reporting problems, requesting modifications, and submitting change proposals. They are a key source of information concerning the status of changes during change processing.

11.4.3.1 Advance Change/ Study Notice

The ACSN (AFSC Form 223) may be

used by the contractor to provide the government with advance information of a proposed change. It describes the item affected, the need for the change, a brief description of the change, alternatives, and a rough cost estimate. The procuring activity, after reviewing the ACSN, will either: 1) reject the change, 2) request additional information, 3) direct an alternate course of action, or 4) authorize the necessary engineering effort to prepare a formal ECP.

11.4.3.2 Engineering Change Proposal

The ECP is used to propose Class I changes to the government. A preliminary ECP may be used in place of an ACSN to obtain government approval to proceed with detailed engineering analysis and design prior to incorporation of a change. The ECP package contains a description of the change, justification, point of effectivity, effect on performance allocation and interfaces, impact on integrated logistic support and operational effectiveness, changes to CI specifications, development requirements and status, and results of trade-off analyses with alternative solutions. If the program is in production, additional data on cost and schedule impact are required. A "not-to-exceed" cost is submitted with a preliminary ECP. If approved by the government, a formal ECP accompanied by a SCN covering exact changes to the CI specification is submitted to the government, together with detailed costs and schedules. The ECP, DD Form 1692, is contained in DoD-STD-480 [6].

11.4.3.3 Specification Change Notice

The SCN is used to propose, transmit, and record changes to a specification. Initially it is used to submit proposed Class I specification change pages, accompanied by an ECP, for government approval. After the proposed documentation change is approved, the SCN is used to transmit the change pages to document holders. The SCN, DD Form 1696, is described in DoD-STD-480 [6].

11.4.3.4 Request for Deviation/ Waiver

A Request for Deviation/ Waiver is used to request and document temporary departures when permanent changes are not acceptable. The requests are usually processed by the CCB. A deviation is written authorization granted prior to product development to permit departure from a particular performance or design requirement for a specified product or period of time. A waiver is written authorization to deliver a configuration item that has been found, after development, to depart from specified requirements, but that nevertheless is considered suitable for use or rework. The Request for Deviation/Waiver, DD Form 1694, is contained in DoD-STD-480 [6].

11.4.3.5 Interface Revision Notice

The Interface Revision Notice (IRN) is used to propose, transmit, and record changes to an ICD. It results primarily from ICWG meetings, and must first be coordinated with and approved by affected parties. The IRN is then transmitted to the CCB. Following approval by the CCB, the IRN is then used to transmit change pages.

11.5 RISK TEMPLATE: CONFIGURATION CONTROL

A common source of risk in the transition from development to production is failure to establish and maintain a strong configuration management system. Direct application of boilerplate policies and/ or invoking military specifications and standards leads to ineffective control or overly complex and costly approaches to managing configuration. In a loosely implemented CM system, design changes can occur without proper maintenance of the configuration change documentation after the baseline is established. Lack of good CM systems leads to many pitfalls, including an unknown design baseline, excessive production rework, poor spares effort, stock purging rather than stock control, and inability to resolve field problems. Poor CM is a leading cause of increased program costs and lengthened procurement schedules. DoD 4245.7-M [9] proposes the following outline for reducing risk:

a. An effective configuration management system should contain the following features:

1. It should be tailored from an effective set of guidelines and standards to fit the nature of the program, including hardware and logistics support elements.

2. Corporate or division policy should recognize the importance of proper CM in the development of a new program, and emphasize the need to generate an adequate plan for implementation.

3. A CMP should be streamlined, yet encompass the entire life cycle of the program, recognizing the requirements of each phase of the acquisition life cycle and the complexity of the system configuration.

4. The CMP should establish the mode of operation and interface relationships among vendors, subcontractors, contractor, and customer.

b. The CM organization should be properly staffed and with individuals having authority commensurate with assigned responsibility.

c. The specification tree, engineering release, and drawing discipline should be managed by documentation requirements established through the CMP.

d. The staff should be trained in the established CM system.

e. The CM program should be disciplined in order to organize and implement, in a systematic fashion, the process of documenting and controlling configuration.

f. Status accounting systems should be updated frequently by timely feedback from user activities.

g. Configuration control procedures should ensure the establishment and maintenance of design integrity.

h. Configuration audits should be performed to establish the design baseline and to validate the drawing package before production release.

i. Manufacturing engineering should interface with configuration control for work

instruction planning.

j. The transition from contractor to government responsibility should be accomplished when the design is largely mature and when field support will be enhanced.

11.6 REFERENCES

1. MIL-STD-483A, "Configuration Management Practices for Systems, Equipments, Munitions, and Computer Programs".

2. DoDD 5010.19, "Configuration anagement".

3. Joint Services Regulation on Configuration Management (AFR 65-3, AR 70-37, NAVELEXINST 4130.1, and MCO 4130.1A).

4. AFSCP 800-7, "Configuration Management".

5. MIL-STD-482A, "Configuration Status Accounting Data Elements and Related Features".

6. DoD-STD-480A, "Configuration Control - Engineering Changes, Deviations, and Waivers".

7. MIL-STD-490A, "Specification Practices".

8. MIL-STD-1521B, "Technical Reviews and Audits for Systems, Equipments, and Computer Software".

9. DoD 4245.7-M, "Transition from Development to Production".

11. DoD-STD-100C, "Engineering Drawing Practices".

12. MIL-STD-1456, "Contractor Configuration Management Plans".

13. DoD-D-1000B, "Drawings, Engineering and Associated Lists".

14. MIL-N-7513F, "Nomenclature Assignment, Contractor's Method for Obtaining".

15. MIL-S-83490, "Specifications, Types and Forms".

16. DoD 4120.3-M, "Defense Standardization Manual".

17. SECNAVINST 4130, "Navy Configuration Management Manual".

CHAPTER 12

TECHNICAL REVIEWS

12.1 INTRODUCTION

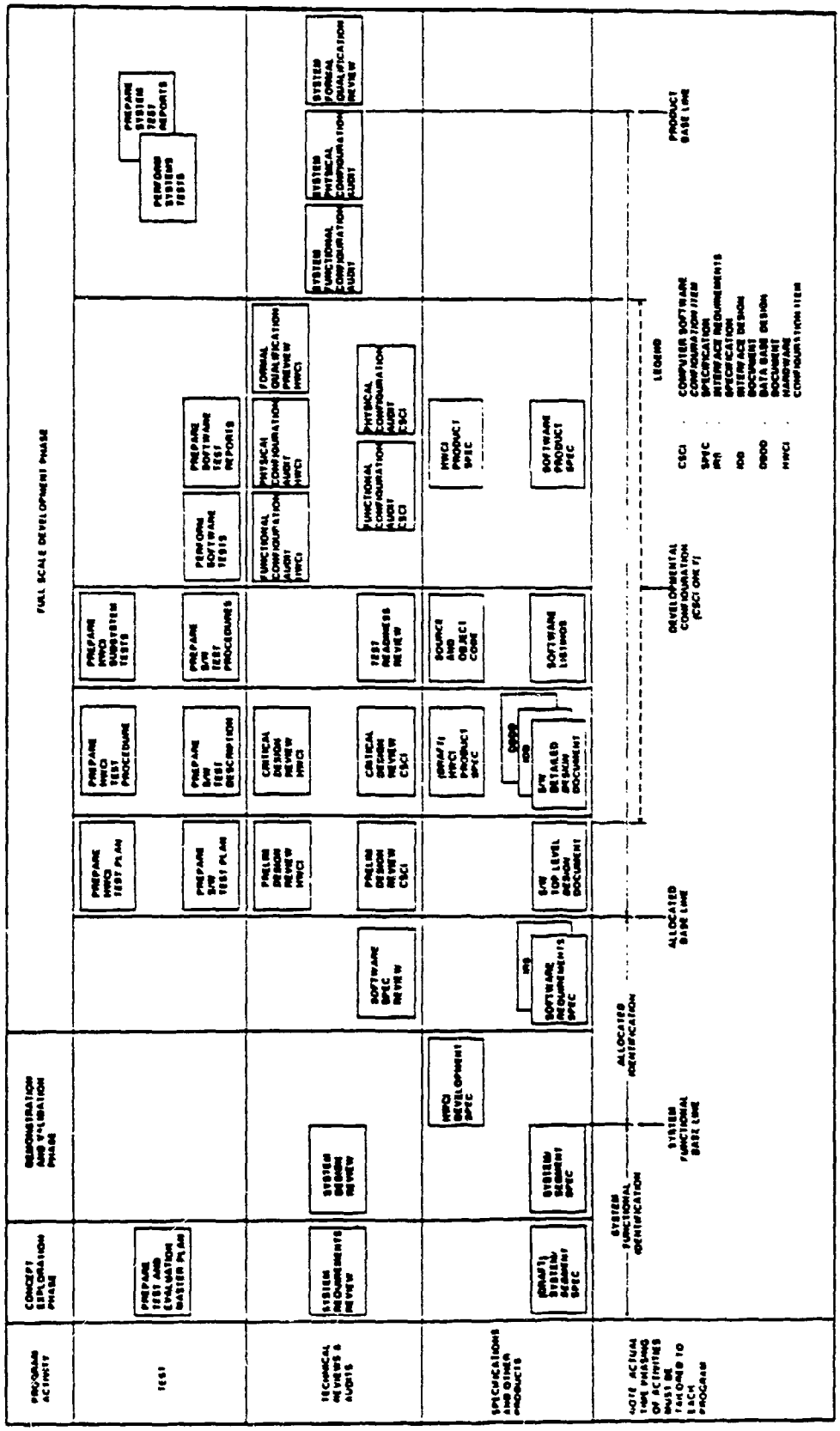
Technical reviews are an integral and essential part of the systems engineering process. These reviews can range from very formal technical reviews by government and contractor systems engineers to very informal reviews concerned with product and/or task elements of the work breakdown structure (WBS) that involve only a few government and/or contractor personnel. All reviews share the common objective of determining the technical adequacy of the existing design to meet known technical requirements. As the acquisition program moves through the life cycle, the reviews become more detailed and definitive. Technical reviews must cover all related engineering specialty disciplines.

Figure 12-1 illustrates the relationship of technical reviews to the system development cycle. Although the systems engineering process is iterative and cannot be precisely related to acquisition phasing, the scheduling of technical reviews depicted on Figure 12-1 indicates the logical time frame for a given system or system segment by acquisition phase. The precise scheduling of all formal technical reviews for each configuration item (CI) or aggregate of CIs will normally be included in the System Engineering Management Plan (SEMP) and in the statement of work (SOW) of the contract. The need for formal reviews is controlled by MIL-STD-1521B [1]. The requirements of this standard should be tailored to such factors as program complexity, level of inherent technical risk, and number of participating contractors. For a non complex system, some reviews may not be required, or if required may be limited in scope. This tailoring should result in development contracts specifying application of a tailored MIL-STD-1521B [1] that reflects a limited scope technical review effort.

The number and depth of formal technical reviews should also be dependent upon the CI technical risk level (new design versus commercially available, or the degree of any modifications). For example, a newly developed item may require the majority of the review topics/ items and audits defined in MIL-STD-1521B [1]. A commercially available CI with the appropriate documentation (e.g., verified test results, specifications, and drawings) may require reviews or audits limited to its application to the program and its interfaces. In the case of modified designs, one must consider the degree of the modifications and effect on technical risk. Reviews and audits may be limited to the modifications and their interfaces.

The schedule for technical reviews and audits is extremely important. If they are conducted too early, the item for review will

Technical Reviews and the System Development Cycle
Figure 12-1



not be adequately defined. Conversely, if the review is too late, the program commitments could have been made erroneously, and correction will be both difficult and costly. A good method for scheduling technical reviews is to relate them to the documentation requirements. For example, schedule a Preliminary Design Review (PDR) after the hardware development specifications (Type B) or software top level design documents and software test plan are available. Scheduling of audits is dependent not only on documentation availability, but also on hardware/ software availability and the completion of the acceptance qualification tests. The time frame for reviews and audits will vary, depending on the requirements associated with a particular program. The schedule for each review or audit should be requested from the offeror as part of the proposal, or as part of the SEMP (which can be part of the proposal).

12.2 FORMAL TECHNICAL REVIEWS

Formal technical reviews conducted in accordance with MIL-STD-1521B [1] include:

a. System Requirements Review (SRR)

The SRR is the first major review. It can be either an internal government or government/ contractor review. The review will focus on mission area analyses (MAA) and systems engineering documentation , in particular the draft system level specification (Type A).

b. System Design Review (SDR)

This review will normally serve as a key transition milestone between the Concept Demonstration/ Validation (D/V) and Full Scale Development (FSD) phases or between the system and lower level development activities. It will focus on more detailed systems engineering documentation, as well as the completed system specification. The SDR provides a review vehicle for data that are used to establish the system functional baseline.

c. Preliminary Design Review (PDR)

This review represents the approval to begin detailed design. Its primary focus is on the adequacy of top level design documentation for hardware and software CIs, and the completeness of the development specifications (Type B), especially for hardware CIs (HWCIs).

d. Software Specification Review (SSR)

The SSR is conducted when the system level computer software requirements have been defined and allocated to computer software configuration items (CSCIs). The primary focus is on the completeness of the CSCI development specifications (Type B-5).

e. Critical Design Review (CDR)

The CDR is generally the transition point between detailed design and fabrication of a CI or aggregate of CIs. Its primary focus is on the completed detailed design documentation and draft product specifications (Type C) for HWCIs and CSCIs.

f. Test Readiness Review (TRR)

The completion of TRR is the program

	WHEN	PURPOSE	DOCUMENTATION/DATA
SRR	LATE C/E	• EVAL SYSTEM FUNCTIONAL REQUIREMENTS • EVAL PROGRAM PLANNING	• DRAFT "A" SPEC • PRELIMINARY PROGRAM DOCUMENTATION - FFBD/ RAS/ MAA
SDR	LATE D/V	• EVAL SYSTEM DESIGN • APPROVE SYSTEM "A" SPEC • ESTAB SYSTEM FUNCTIONAL BASELINE	• "A" SPEC • DRAFT "B" SPECS • DESIGN DOCUMENTATION • RAS/ SBD/ TLS
SSR	EARLY FSD (Prior to S/W PDR)	• EVAL S/W PERFORMANCE REQUIREMENTS • APPROVE S/W DEVELOPMNET "B-5" SPECS • ESTAB S/W ALLOCATED BASELINE	• "B-5" SPECS • OPERATIONAL CONCEPT DOCUMENT
PDR	EARLY FSD	• EVAL PRELIMINARY DESIGN • APPROVE H/W DEVELOPMENT "B" SPECS • ESTAB H/W ALLOCATED BASELINE (Conducted for both H/W & S/W CIs)	• "B" SPECS • TOP LEVEL CI DESIGN DOCUMENTATION • TEST PLANS • ICD/ ENG DRAWINGS
CDR	EARLY/MID FSD	• EVAL DETAILED DESIGN • DETERMINE READINESS FOR H/W FABRICATION • DETERMINE READINESS FOR S/W CODING (Conducted for both H/W & S/W CIs)	• DRAFT "C, D, & E" SPECS • CI DETAILED DESIGN DOCUMENTATION
TRR	MID/LATE FSD	• APPROVE S/W TEST PROCEDURES • DETERMINE READINESS FOR CSCI TESTING	• S/W TEST PLAN & PROCEDURES • INFORMAL S/W TEST RESULTS
FQR	LATE FSD	• VERIFY CIs PERFROM IN THE SYSTEM ENVIRONMENT	• "A, B, & C" SPECS • TEST RESULTS/ REPORTS • OPERATIONAL/ SUPPORT DOCUMENTATION
PRR	FSD	• ASSESS RISK FOR PRODUCTION GO-AHEAD (Conducted incrementally throughout FSD)	• PRODUCTION PLANNING DOCUMENTATION

Technical Review Summary
Figure 12-2

event coincident with the initiation of the formal CSCI testing. Its primary focus is on the adequacy of the software test procedures.

Figure 12-2 identifies the principal technical reviews. More detail on each review is provided in the following paragraphs.

12.2.1 System Requirements Review

SRRs are normally conducted during the C/E or D/V phases after the system level functional analysis has been performed and the system level requirements have been allocated. The purpose of the review is to ensure that system requirements have been completely and properly identified and that there is a mutual understanding between the government and the contractor on system requirements. Particular emphasis is placed on ensuring that adequate consideration has been given to logistic support, software, test, and production constraints.

The primary documents used in this review are products of the functional analysis, synthesis, and trade studies: functional flow block diagrams (FFBDs), requirements allocation sheets (RASs), and time line sheets (TLSs), supplemented by MAA, and system simulations (e.g., relating to survivability/vulnerability (S/V) or reliability/ availability/ maintainability (RAM)) at the most general level. Traceability of allocated requirements to the capability of the system to meet the mission need and program objectives within planned resource constraints must be demonstrated by correlation of technical and cost information through the WBS. Specific items to be reviewed include:

a. MAA

b. System level FFBDs, TLSs, and RASs

c. System trade studies including system effectiveness and life cycle cost

d. Independent cost evaluation (ICE)

e. System interface studies

f. Preliminary manufacturing plans

g. Manpower requirements plans

h. Milestone schedules.

The technical documentation that is the subject of this review, primarily the system level specifications (Type A), is used to establish the formal system functional baseline.

12.2.2 System Design Review

The SDR is the final review before submittal of D/V phase products. This may be the initial FSD phase review for systems that do not require a formal D/V phase but are sufficiently complex to warrant formal assessment of the allocated requirements.

The focus of the SDR is to evaluate the optimization, traceability, correlation, completeness, and risk of the system level design to fulfill the system functional baseline requirements. The review encompasses the total system requirements (e.g., operations, maintenance, test, and training) for hardware, software, facilities, personnel, and preliminary logistic support considerations. This is a

review of systems engineering activities that yield products defining the system level:

a. Mission and requirements analysis

b. Functional analysis

c. Requirements allocation

d. Manufacturing methods/ process selection

e. Program risk analysis

f. System effectiveness analysis

g. Logistics support analysis (LSA)

h. Trade studies

i. Intra- and inter-system interface studies

j. Integrated test planning

k. Engineering specialty discipline studies

l. Configuration management plans.

A technical understanding is reached on the validity and the degree of completeness of the system level design, specification, and acquisition and life cycle cost estimates. The formal system functional baseline is normally established at SDR once the system specification (Type A) is approved.

12.2.3 Preliminary Design Review

PDRs are conducted for each CWCI and CSCI after top level design efforts are completed, but prior to the start of detailed design. They may be held after the approval of the development specifications, or their approval may be accomplished at the PDR, which is normally the case. Either way, completion of the PDR represents approval to begin detailed design. A design review is not considered formally complete until the contracting agency provides formal acknowledgement indicating approval or contingent approval pending satisfactory completion of resultant action items.

A PDR is held for each CI or a functionally related group of CIs prior to the system level review. Overall technical risks for each item are reviewed. Appropriate emphasis is given to review of the preliminary design of all system elements: hardware, software, personnel, facilities, and procedural data. Principal documentation for this review is the development specification (Type B) and top level design documents. Traceability of all specified technical requirements should be demonstrated, through systems engineering documentation to the allocated baseline. Typical items to be reviewed include:

a. Development specifications (Type B)

b. Preliminary design synthesis of development specifications

c. Trade studies and design studies supporting preliminary design of CIs

d. Lay-out drawings for CIs

e. Engineering specialty studies (e.g., RAM, safety, integrated logistic support (ILS), producibility, and human engineering)

f. Interface requirements for

developmental HWCIs

g. Mock-ups, models, breadboards, and prototype hardware

h. Systems engineering documentation (e.g., FFBD, RAS, DS, and SBD) required to support review of the development specifications

i. Initial identification of development specifications support equipment items (e.g., testing consoles and power equipment)

j. Computer software top level design and computer software test plan.

During the PDR, special attention is directed toward interface documentation, high risk areas, long lead times, and system level trade studies that integrate preliminary design concepts. The government reviews the progress of the systems engineering process by examining the description of proposed system elements to ensure that the system design optimization trade-offs fully integrate the operations, logistic support, test, production, and deployment requirements. In instances where a contractor has identified the requirement for government furnished equipment (GFE) in the Department of Defense (DoD) inventory, the government will also validate the availability of those items.

12.2.4 Software Specification Review

An SSR for each CSCI will be conducted after the SDR, but prior to initiation of top level design for each individual CSCI. These reviews are keyed to the overall system development cycle and they must follow after system level hardware/ software allocation decisions are made. An SSR may be conducted prior to or after a hardware PDR depending on the relationship between a particular CSCI and HWCI; in all cases, however, an SSR will be conducted before the PDR for that particuler CSCI.

The purpose of this review is to establish the formal allocated baseline for each CSCI. Emphasis is on demonstrating the adequacy of the software requirements specification, interface requirements specification, and the operational concept document.

12.2.5 Critical Design Review

A CDR is conducted for each HWCI and CSCI before release of design for fabrication. For CSCIs, the CDR is conducted before coding and informal software testing. For large, complex systems, the CDR may be a progressive or incremental review of CIs culminating in a system level CDR that essentially reviews the completeness of preceding CDRs and ensures adequate interfaces.

During the CDR, the detailed design for each CI is disclosed in the form of a draft product specification (Type C) and related engineering drawings. The approved detailed design from this review serves as a basis for final production planning and often initial fabrication. In the case of software, the completion of the CDR initiates the development of source and object code. The review establishes the integrity of the CSCI's logical design prior to coding and testing. Typical items reviewed at the CDR include:

a. Draft Type C, D, and E specifications

b. Detailed engineering drawings

c. Interface control drawings

d. Prototype hardware

e. Manufacturing Plan

f. Quality Assurance Plan.

CDRs are the last major design reviews and their timing controls many pre-production tasks which must be initiated to prepare for the transition from FSD to Production. The correct timing of CDRs is critical. A balance must be found between technical and production concerns. For example, closing out CDRs early can provide more time for production but could reduce the time available for production planning. In other words, the lack of full maturity of the designs reviewed will increase the risk that the number of post review changes will adversely affect production planning. Closing out CDRs too late may severely constrain production schedules and the ability to obtain adequate competition.

12.2.6 Test Readiness Review

The TRR is a formal review of the contractor's readiness to begin CSCI testing. It is conducted for each CSCI after informal testing at the computer software component (CSC) and computer software unit (CSU) level for that CSCI has been completed. Its purpose is to allow the government to 1) determine that the contractor is prepared to begin formal testing at the CSCI level in accordance with the appropriate software test procedures, 2) reach a technical understanding on the validity of informal test results, and 3) determine the adequacy of the software operations and support manuals. Items reviewed at the TRR include:

a. Software test procedures (STPR)

b. Draft Computer System Operator's Manual (CSOM)

c. Draft Software User's Manual (SUM)

d. Informal CSC and CSU test and integration results

As it is currently defined, the TRR does not involve any specific systems engineering products. However, in a manner similar to all other reviews, the contractor should demonstrate that the functions to be tested are those allocated to software in the underlying technical documentation, and that requirements for software timing and software performance will support the defined mission functional requirements.

12.2.7 Functional Configuration Audit

The objective of the Functional Configuration Audit (FCA) is to verify that the CI's actual performance complies with its hardware/ software development and interface requirements specifications. Test data are reviewed to verify that the hardware and software performs as required by its functional/ allocated configuration identification. For software, a technical understanding is reached on the validity and the degree of completeness of the Software Test Reports (STR), and as appropriate,

updates of the CSOM and SUM.

The FCA for a complex CI may be conducted on a progressive basis throughout the CI's development. The process then culminates after the completion of the qualification testing of the CI with a review of all CI discrepancies at the final system level FCA. The FCA must be conducted on the CI (whether production, prototype, or pre-production) representative of the configuration to be released for production of the operational inventory quantities. When a prototype or pre-production article is not produced, the FCA will be conducted on a first production article. For cases where CI qualification can only be determined through integrated system testing, FCAs for such CIs will not be considered until integrated system testing is complete.

12.2.8 Physical Configuration Audit

The Physical Configuration Audit (PCA) is the formal examination of the as built version of a CI against its Type C, D, and E specification documentation, in order to establish the product baseline. After successful completion of the audit, all subsequent changes are processed by engineering change action. The PCA also determines that the acceptance testing requirements prescribed by the documentation are adequate for acceptance of production units of a CI by quality assurance activities.

The PCA includes a detailed audit of engineering drawings, specifications, technical data and tests utilized in production of hardware CIs, design documentation, code listings, and manuals for CSCIs. The review also includes an audit of the released engineering documentation and quality control records to make sure the as built or as coded configuration is reflected by this documentation. For software, the software product specification and version description document (VDD) shall be a part of the PCA review.

In complex systems containing many CIs, the scope of an audit may be such that it must be broken apart to ensure effective participation of both contractor and government personnel. One approach used is to break the audit into three stages:

a. Stage 1: Review of Production Baseline

b. Stage 2: Operational Audit

c. Stage 3: Government Acceptance of the Product Baseline

The PCA is conducted on the first CI production article. It is also conducted on those items that are a reprocurement of a CI already in the inventory. A PCA must be conducted on the first CI to be delivered by a new contractor even though a PCA was previously accomplished on the first article delivered by a different contractor. Formal approval by the contracting agency of the CI product specification (Type C), and the satisfactory completion of a PCA, results in establishment of the product baseline for that CI.

12.2.9 Production Readiness Review

The objective of the Production Readiness Review (PRR) is to determine if the design is ready for production, production

engineering problems have been resolved, and adequate planning has been accomplished for the production phase. The PRR represents the point where a production commitment can be made without incurring unacceptable program risk. PRRs should be conducted, by the systems engineer, as a time phased effort that will span FSD and encompass the developer/ producer and major subsystem suppliers. The PRR examines the developer's design from the standpoint of completeness and producibility. It examines the producer's production planning documentation, existing and planned facilities, tooling and test equipment, manufacturing methods and controls, material and manpower resources, production engineering, quality control and assurance provisions, production management organization, and controls over major subcontractors. The result of the PRR supports the systems engineer's affirmative decision at the production decision point - that the system is ready for efficient and economical rate production. DoDI 5000.38 [2] identifies the requirements and criteria for these reviews. Further detail on the PRR is provided in Chapter 18 of this guide.

12.2.10 Formal Qualification Review

The objective of the Formal Qualification Review (FQR) is to verify that the performance of the CIs, when integrated into a system, meets all system functional requirements and, in fact, do properly function together as a system. The FQR will identify the test report(s)/ data that document the qualification test results of the CIs to show compliance with the system specification, hardware development specifications, software requirements specifications, and interface requirements specifications. Essentially, the FQR is a system level configuration audit, conducted after full up system testing is completed.

When required, the FQR shall be combined with the FCA at the end of CI/ subsystem testing, prior to PCA. If sufficient test results are not available at the FCA to ensure that CIs will perform in their system environment, or deployed operational experience data are required, the FQR will be conducted (post- PCA) during follow on operational testing and evaluation whenever the necessary tests have been completed. For non-combined FCAs/ FQRs, traceability, correlation, and completeness of the FQR must be maintained with the FCA and duplication of effort must be avoided. For software, a technical understanding must be reached on the validity and degree of completeness of the Software Test Reports, and as appropriate, updates of the CSOM and SUM should be audited.

The point of government certification will be determined by the contracting agency, and will depend upon the nature of the program, risk aspects of the particular hardware and software, and contractor progress in successfully verifying the requirements of the CIs. A logical time to schedule an FQR would be between developmental and operational testing of the system, prior to the contractor turning the system over to the government.

12.3 INFORMAL REVIEWS

Informal reviews may include technical interchange meetings called either by the government or the contractor to investigate

and resolve specific technical issues. Although lower level reviews are held on an informal basis, they still require an agenda prepared by the contractor and transmitted to the government in time for a team to be assembled and briefed. The informal engineering review should be preceded by a data package from the contractor containing applicable engineering drawings, specifications, and reports. Meetings must be scheduled to ensure that required technical experts will be available. The use of material prepared directly by engineers should be encouraged, rather than formally prepared material. At the conclusion of the review, a summary of actions and approvals should be prepared for presentation at the subsequent formal review. Issues, questions, agreements, and action items must be documented in minutes and assigned, tracked, and coordinated with appropriate participants through close out or completion.

Informal engineering reviews are not the proper forum for considering changes to baselines or for initiating engineering change proposals (ECPs). Review of changes should be reserved for Configuration Control Board (CCB) meetings following, or coinciding with, formal technical review meetings. This assures that a broad representation of management and technical disciplines will be involved in the review and approval of engineering change proposals.

12.4 TECHNICAL REVIEW ADMINISTRATION

In developing the request for proposals (RFP) for any acquisition phase, it is necessary for the government to identify specific technical reviews to be imposed on the program. This is generally done by tailoring MIL-STD-1521B [1] to fit program needs. MIL-STD-1521B [1] provides extensive lists of topics to be reviewed for HWCIs and CSCIs; support equipment; electrical, mechanical, and logical designs; RAM; and many other design characteristics. The lists should be used to develop technical review agendas tailored to specific characteristics of the program.

The RFP will also identify as contract data requirements list (CDRL) items the appropriate technical review data item descriptions (DIDs). These include technical review agenda, DI-A-3029 [3]; technical review data package, DI-E-5423 [4]; and the minutes of formal reviews, DI-E-3118 [5]. The contractor is responsible for developing the design review agenda and transmitting it to the government program office 30 to 45 days before the meeting. The systems engineer notes any changes in content and approves the final agenda. The contractor prepares the technical review data package and transmits it to the government, as specified in the CDRL, two or more weeks before the meeting. Following review of the data package, questions from the team are coordinated by the systems engineer and transmitted to the contractor before the meeting, as contractually specified.

The success of a review depends on both government and contractor preparations before the meeting. It is important that the technical review teams be composed of personnel competent to cover all areas to be reviewed and that the government members have sufficient time available to review the planned agenda and data package before the meeting. Technical reviews should not be tutorial sessions. Personnel training is not

the objective of technical reviews. All government participants should meet before the scheduled review to acquaint themselves with material being reviewed, objectives of the review, and the approach to be used in the review. Review personnel/ teams should be specifically chartered by the systems engineer to cover specific areas, documents, or subjects. It is essential that the teams be held to the minimum number of personnel to adequately cover the areas of the review so that excessive time is not spent on discussion. A list of authorized government attendees is provided to the contractor prior to the meeting to control participation, ensure qualified personnel, and observe appropriate security regulations.

The government and contractor systems engineers act as co-chairmen of the technical review. The government ensures that all areas are adequately examined and provides coordinated comments and direction to the contractor. Only the designated co-chairmen have decision making responsibilities, so they must be thoroughly familiar with all aspects of the program before the review convenes. A concerted effort must be made to avoid an adversarial relationship, which sometimes results from pressures of program schedule and funding limits. Candor and objectivity should be encouraged among all participants. Teamwork should be stressed. The objective of the technical review is to search out design weaknesses or faulty designs. This can be accomplished through healthy skepticism, not through an adversary role. A properly selected/ prepared review team can provide invaluable assistance to the contractor's systems engineering/ design teams in refining trade-offs and synthesizing design or production alternatives. Problems should be identified early from the data package submittal and attempts should be made to clarify them on an individual basis before the review. Avoid presenting major problem surprises at the meeting. This saves meeting time and helps maintain positive attitudes.

Decisions, agreements, and approved action items should be recorded and signed by both the government and the contractor at the end of each day. Each action item should be assigned to responsible individuals (one government, one contractor), with an assigned closure date and the type of response required to close the action. The co-chairmen should evaluate proposed actions to ensure that they are not out of contract scope. Out of scope changes must be handled by contracting officers in accordance with applicable procurement regulations and CCB procedures.

After each formal technical review, the minutes of that review are published for distribution. The minutes identify the proceedings of the review, as well as action items, for accomplishment/ resolution. The government provides formal acknowledgement to the contractor of the accomplishment of each review after receipt of the review minutes and satisfactory close out of all outstanding action items. The government establishes the adequacy of the contractor's review performance by notification of approval, contingent approval (review will be accomplished upon satisfactory completion of the action items), or disapproval (indicating that the review was seriously inadequate). It should be noted that formal technical review completion is a good indicator of overall

program status. Slippage in review schedules will often lead to slippage in overall program plans including scheduling of major acquisition milestones.

12.4.1 Technical Review Documentation

The technical review data package consists of documentation developed by the contractor according to DID DI-E-5423 [4] during the development process, and may include the following:

a. Specifications

b. Configuration and lay-out drawings

c. Analysis and simulation reports

d. Trade study reports

e. FFBDs, RASs, TLSs, SBDs, DSs

f. Plans

g. RAM data

h. Survivability/ Vulnerability (S/V) data

i. Verification data.

If more data are requested than can or should be reviewed by the systems engineer in the time available before the review, an unnecessary cost is incurred and review credibility is lost. Coordination with the contractor is therefore required to ensure the efficiency of providing only needed data.

12.4.2 Technical Review Meeting Minutes

Technical review meeting minutes are prepared by the contractor according to DID DI-E-3118 [5] and should include the following:

a. Narrative summary of significant comments, findings, decisions, and direction provided at the meeting, with rationale where appropriate

b. Meeting agenda

c. List of data package contents

d. List of attendees

e. Action items with responsibilities and due dates

f. List of presentation material.

12.5 RELATION OF TECHNICAL REVIEWS TO PROGRAM SPECIFICATIONS

Program specifications are the basic tools for establishing the formal baselines during the development cycle. Figure 12-2, shown previously, summarizes the preceding technical reviews, related general schedules, and specifications for hardware and software development that are primary candidates for review. Generally speaking 1) the system functional baseline is normally established at the SDR and is represented by the approved system specification (Type A); 2) the allocated baselines for HWCIs are normally established at their PDRs, but no later than their CDRs and are represented by their approved development specifications (Type B); 3) the allocated baselines for CSCIs are normally established at their SSRs and are represented by their approved

developmental specifications (software requirements and interface requirments specifications; Type B-5); and 4) the product baselines for HWCIs and CSCIs are normally established at their PCAs and are represented by their product specifications (Type C). For greater detail on the development of program specifications, see Chapter 10 of this guide.

12.6 RISK TEMPLATE: TECHNICAL REVIEWS

The application of technical review requirements involves the balancing of many factors. The timing of reviews, scope of review, government and contractor personnel who participate, and preparation of personnel are all factors that may lead to successful or unsuccessful implementation. While defense contracts usually require formal technical reviews, they often lack specific direction and discipline in the technical review requirement, resulting in an unstructured review process that fails to fulfill either of the two main purposes of technical review, which are: (1) to bring additional knowledge to the design process to augment the basic program design and analytical activity; and (2) to challenge the satisfactory accomplishment of specified design and analytical tasks needed for approval to proceed with the next step in the acquisition process. DoD 4245.7-M [6] recommends the following measures for reducing risk:

a. Government and contractors should recognize that technical reviews represent the "front line" for determining program readiness to transition to the next development phase. Technical review policy, schedule, budget, agenda, participants, actions, and follow-up should be decided in view of this need.

b. A technical review plan outlining the schedule of reviews should be developed by the contractor and approved by the government. The technical review plan should include both government and internal contractor technical reviews and inspections.

c. Techncial review requirements should be allocated to subcontractors and suppliers to ensure proper subcontractor internal technical review practices and to provide timely opportunities for both the contractor and government to challenge subcontracted material design.

d. Government and contractor techncial review participants should be selected or recruited from outside the program to be reviewed, on the basis of experience and expertise in challenging the design. They should have a collective technical competence greater than or equal to that of the designers responsible for the design under review.

e. Manufacturing, product assurance, and logistics engineering functions should be represented and have authority equal to engineering in challenging design maturity.

f. Technical reviews should use computer-aided design analyses, whenever available, and include review of production tooling required at the specific program milestone.

12.7 SUMMARY

A summary of major areas of

Major Technical Review Concerns
Figure 12-3

Timing/Scheduling

- Do design reviews support program milestone decisions?
- Do technical reviews and audit schedules consider the availability of appropriate program documentation, hardware, software, and test results?
- Are design reviews scheduled late enough to ensure adequate design definition?
- Are design reviews scheduled early enough to avoid costly corrections to the design?

Tailoring/Scope

- Have the design review requirements of MIL-STD-1521B been tailored to program needs?
- Have data requirements supporting reviews been tailored so that only necessary data are produced before, during, and after the review?
- Are the right data available to make decisions required by the review?
- Is the scope of the review appropriate to the stage of design maturity?
- Is the scope of the review adequate to accomplish review objectives?

Personnel

- Are all appropriate government and contractor personnel scheduled to participate in each review?
- Are all personnel familiar with the topics to be covered, and are they prepared for the review?
- Is the review team small enough to focus the discussion?

Administration

- Does the action item list prepared during the review assign each action to an individual responsible for its resolution within a specified time period?
- Is the effort to close out the review reasonable?

management concern is shown in Figure 12-3. There are no easy guidelines to achieving an optimum balance among these factors. Timing, scope, and personnel contribute greatly to the success of technical reviews.

12.8 REFERENCES

1. MIL-STD-1521B, "Technical Reviews and Audits for Systems, Equipments, and Computer Software".

2. DoDI 5000.38, "Production Readiness Reviews".

3. DI-A-3029, "Agenda - Design Reviews, Configuration Audits and Demonstrations".

4. DI-E-5423, "Design Review Data Package".

5. DI-E-3118, "Minutes of Formal Reviews, Inspections and Audits".

6. DoD 4245.7-M, "Transition from Development to Production".

CHAPTER 13

ROLE OF TEST AND EVALUATION IN THE SYSTEMS ENGINEERING PROCESS

13.1 INTRODUCTION

In the early 1970s, Department of Defense (DoD) test policy became more formalized and placed greater emphasis on test and evaluation (T&E) as a continuing function throughout the acquisition cycle. These policies stressed the use of T&E to reduce acquisition risk and provide early and continuing estimates of the system's operational effectiveness and operational suitability. In order to meet these objectives, it is necessary that appropriate test activities be fully integrated into the overall development process. From a systems engineering perspective, test planning, testing, and analysis of test results are integral parts of the basic systems engineering process.

The integration of T&E requirements has several dimensions which includes two broad categories of testing: 1) government and 2) contractor. Government tests can be further categorized as user tests, which are broadly operational in emphasis, and builder tests, which focus on achievement of development requirements.

Another perspective of T&E requirements shows that test and evaluation encompasses relationships with all system elements: equipment, software, facilities, personnel, and procedural data. Each work breakdown structure (WBS) element must receive appropriate T&E. In most cases (e.g., software) the system element may have unique requirements which constrain the approach taken to testing.

Another T&E dimension to consider is that testing spans the overall acquisition life cycle. It is not simply something that takes place when development is complete. Finally, as T&E requirements are identified for the operation (and support) functions, the systems engineering process can also be used to identify the system elements (resources and procedures) necessary for the test activities themselves.

T&E policy, described in DoDD 5000.3 [1], provides guidelines for planning and conducting test and evaluation. It defines and describes the major categories of Development Test and Evaluation (DT&E) and Operational Test and Evaluation (OT&E), and provides for exceptions such as combining DT&E with OT&E, T&E for special acquisition programs, T&E of computer software, T&E of system alterations, and joint T&E programs. DoDD 5000.3 [1] specifies three general requirements:

a. Successful accomplishment of T&E objectives will be a key requirement for decisions to commit significant additional resources to a program or to advance it from

one acquisition phase to another.

b. T&E shall begin as early as possible and be conducted throughout the system acquisition process to assess and reduce acquisition risks, and to estimate the operational effectiveness and operational suitability of the system.

c. The dependence on subjective judgement of system performance will be minimized during testing.

The direct reporting responsibilities of the Deputy Director Defense Research and Engineering (Test and Evaluation) DDDRE(T&E) and the Director, Operational Test and Evaluation (DOT&E). The general organization for DoD T&E is illustrated in Figure 13-1.

DoDD 5000.3 [1] is supported by five manuals (see References [2] through [5]) in the areas of:

a. Test and Evaluation Master Plans (TEMPs).

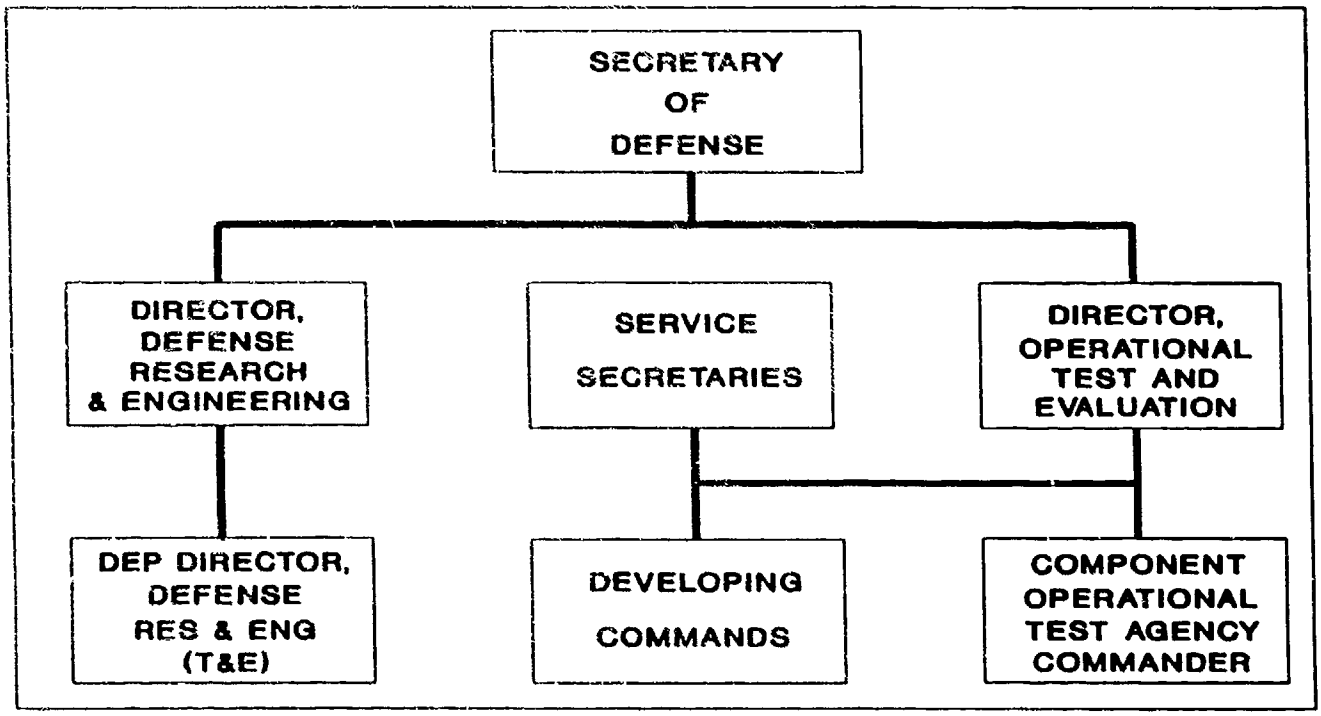
b. DoD NATO comparative tests and foreign weapons evaluation.

c. Software T&E.

d. Joint T&E procedures.

e. DT&E support of major weapon systems operational testing.

In summary, there is clear policy stating test and evaluation program requirements, with particular emphasis on those programs



DoD T&E Organizational Structure
Figure 13-1

designated as major weapon systems. Test and evaluation is an integral part of the systems engineering management process. It begins early and extends throughout the acquisition life cycle. The most general objectives of the Test and Evaluation program are 1) to assess and reduce the risk to the program and 2) to estimate the operational suitability and effectiveness of the system.

13.2 TESTING

Test and evaluation (T&E) is conducted throughout the system acquisition life cycle. There are two major categories of T&E: 1) Development Test and Evaluation (DT&E) and 2) Operational Test and Evaluation (OT&E). Figure 13-2 shows how DT&E and OT&E are integrated into the acquisition life cycle.

13.2.1 Developmental Test And Evaluation

Development test and evaluation (DT&E) is conducted throughout the acquisition process to ensure the acquisition and fielding of an effective and supportable system. DT&E includes test and evaluation of components and subsystems at all work breakdown structure (WBS) levels including preplanned product improvement (P^3I) changes, hardware/ software integration, and related software, as well as qualification, live fire, and production acceptance testing. It involves the use of simulations, models, breadboards, brassboards, and testbeds, as well as full scale engineering development models or prototypes of system components or the system itself.

DT&E is normally planned, conducted, and monitored by the developing agency. DT&E is conducted to:

a. Assist the engineering design and development process

b. Verify performance objectives and specifications

c. Demonstrate that design risks have been minimized

d. Estimate the system's military utility when introduced

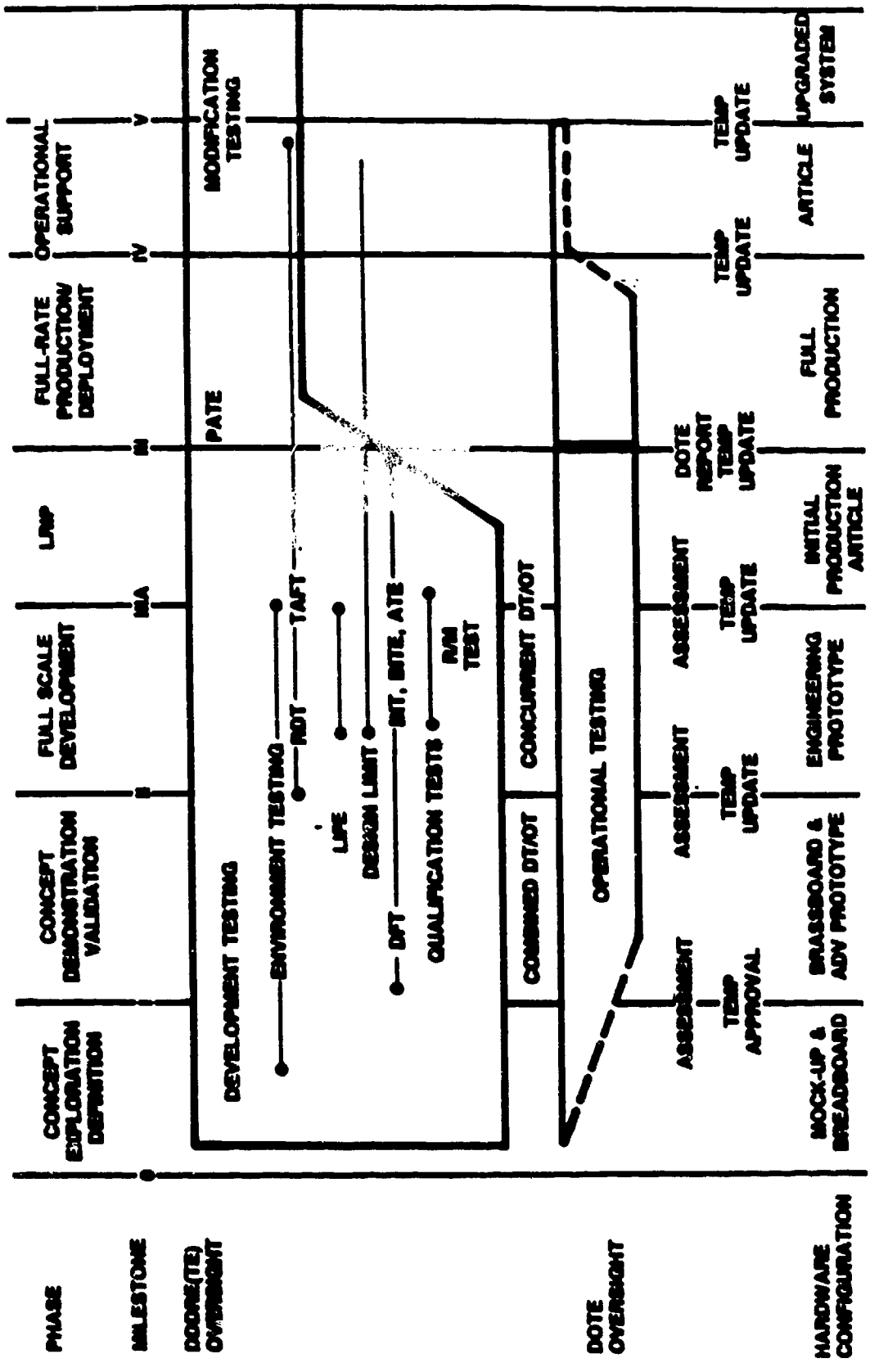
e. Evaluate the compatibility and interoperability with existing or planned equipment/ systems

f. Provide an assurance that the system/ equipment is ready for testing in the operational environment.

DT&E is divided by acquisition phase. It is often abbreviated "DT". Since each phase of DT supports the next milestone decision, it must be completed and documented far enough in advance so that the results can be used in reaching that decision. End-of-phase test reports for major defense acquisition programs must be provided to the DOT&E and DDRE(T&E) least 45 days prior to a milestone decision or the final decision to proceed beyond low-rate initial production (LRIP).

DT is conducted 1) during the Concept Exploration/ Definition (C/E) phase to assist in selecting preferred alternative system

Figure 13-2
Testing in the Acquisition Process



concepts, technologies, and designs; 2) during the Concept Demonstration/ Validation (D/V) phase to identify and validate the preferred technical approach, including the identification of technical risks and feasible solutions; 3) during the Full Scale Development (FSD) phase to demonstrate that engineering is reasonably complete, that all significant design problems have been identified and solutions to these problems are in hand, and that the design meets its required specifications in all areas (such as performance, reliability, and maintainability) within the range of environmental parameters designed for the operational employment of the system; and 4) after the Milestone III (Production and Deployment) Decision. It is an integral part of the development, validation, and introduction of system changes undertaken to improve the system, to react to new threats, and/ or to reduce life cycle costs.

As part of DT, each developing agency is also responsible for the qualification testing that verifies the design and the manufacturing process and provides a baseline for subsequent acceptance tests. Qualification tests consist of pre-production and production qualification tests.

Pre-production qualification tests are formal contractual tests that ensure design integrity over the specified operational and environmental range. These tests usually use pre-production or prototype hardware fabricated to the proposed production specifications and drawings. Such tests include reliability and maintainability demonstration tests required prior to production release. Pre-production qualification testing must be completed prior to Milestone III as it is a critical factor in assessing the system's readiness for production.

Production qualification tests are conducted for all production items to ensure the effectiveness of the manufacturing process, equipment, and procedures. All new production items are subjected to first article test to verify specification compliance and form, fit and function. Production acceptance tests are conducted on each item or on a sample lot taken at random from each production lot. These tests are repeated when the process or design is changed significantly, and when a second or alternate source is brought on line. Production qualification tests are also conducted against contractual requirements.

13.2.2 Operational Test and Evaluation

For major systems, OT&E is normally planned and conducted by a major OT&E field agency located within the DoD component. This Operational Test Agency (OTA) must be separate and independent from both the developing/ procuring agency and the using agency. The OTA is responsible for managing operational testing, reporting test results, and providing directly to the Military Service Chief or Defense Agency Director its independent evaluation of the system being tested. The principal objectives of OT&E are to:

a. Estimate the operational effectiveness and operational suitability of the system.

b. Identify needed modifications or improvements.

c. Provide the information on tactics, doctrine, organization, and personnel requirements.

d. Provide data to uphold or verify the adequacy of various manuals, handbooks, supporting plans, and documentation.

Although OT&E is planned and conducted by an independent testing activity, the Program Manager (PM) must closely coordinate all aspects of test and evaluation with this organization to ensure that DT&E objectives coincide with OT&E objectives.

OT&E is conducted in an environment as operationally realistic as possible. Typical operation and support personnel will be used to obtain a valid estimate of the user's capability to operate and maintain the system when deployed under both peacetime and wartime conditions. The system contractor is precluded by public law 99-661 from participating in realistic operational test and evaluation. OT&E is often abbreviated "OT". Each phase of OT, like DT, supports the next milestone decision.

OT is conducted 1) during C/E to estimate the operational impact of candidate technical approaches and to assist in selecting preferred alternative system concepts. Most acquisition programs will require early operational assessments (EOA); 2) during D/V to examine the operational aspects of the selected alternative technical approaches, estimate the potential operational effectiveness and suitability of the candidate system, and identify operational issues for the early operational assessment and FSD OT; 3) during FSD to demonstrate the system's operational effectiveness and suitability. The items tested must sufficiently represent expected production models to ensure that a valid assessment of the system can be made. The development of tactics for operational employment of the system within the range of environmental parameters should be well underway; and (4) after Milestone III, but before the production system is ready for testing. Normally, limited follow-on OT will use the same system and support equipment used in the operational evaluation and will test the fixes to be incorporated in production systems, complete deferred or incomplete pre-production test and evaluation, and continue tactics development. FOT&E will continue until the objectives specified in the approved TEMP for this phase have been met, regardless of the date of deployment of production systems.

FOT&E is conducted on production systems to validate the achievement of the program objectives for production system operational effectiveness and suitability. Other OT testing may include OT of the existing system in a new environment, with a new subsystem, in a new tactical application, or against a new threat.

Since DT and OT take place during the same phases of the acquisition cycle, it may make sense to coordinate early DT and OT testing to use resources more efficiently in obtaining the data necessary to satisfy the common needs of both the developing agency and OTA. This is called combined testing. Development and operational tests can be combined when significant, clearly identified cost and time benefits will result. Of course,

the test objectives of both the developing agency and OTA will have to be reflected in this combined testing situation.

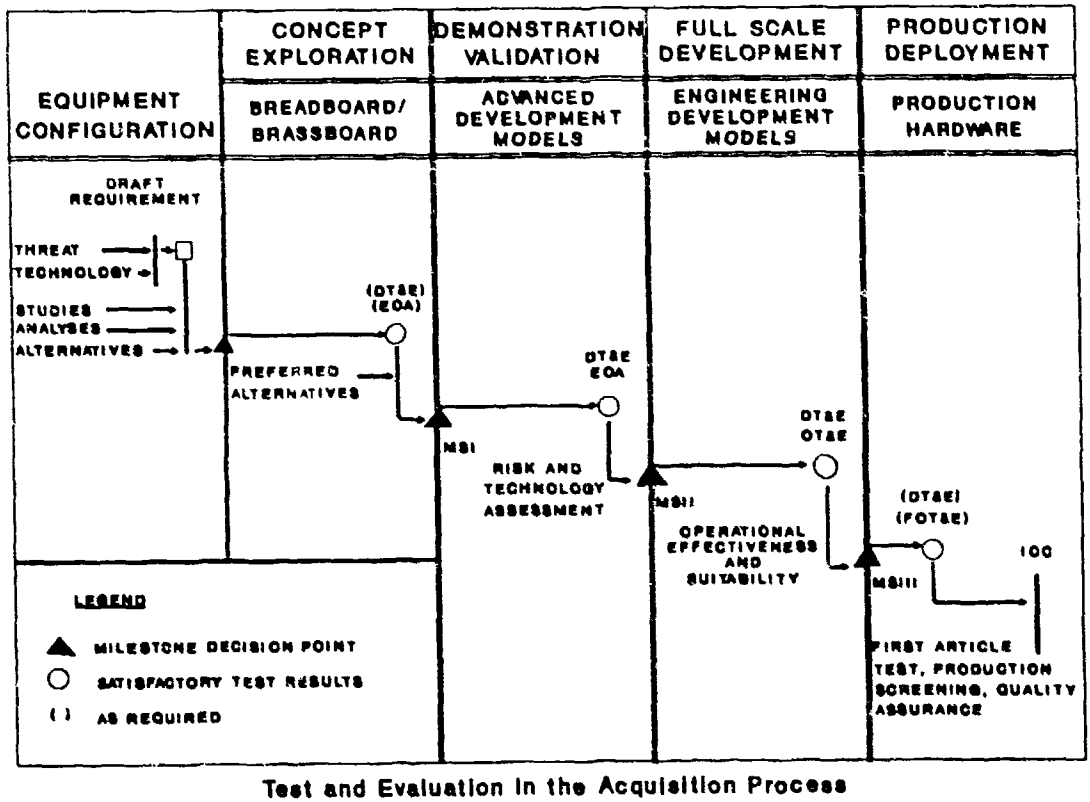
One important note: The FSD subphases of DT technical evaluation and OT operational evaluation should not be combined.

13.3 APPROACH

Although all acquisition programs are tailored to system requirements, they generally follow a sequence similar to that illustrated in Figure 13-3. The C/E phase considers various ways of satisfying the operational requirement and identifies the preferred alternative or alternatives. Often it includes test requirements related to advanced technology.

The D/V phase results in the fabrication and test of functional hardware. Test and evaluation during this phase validates the approach and demonstrates that equipment or systems can be built to meet the operational requirements.

FSD produces the full scale engineering development or service test models that



Test and Evaluation in the Acquisition Process
Figure 13-3

closely approximate the expected production articles. These models are used for rigorous test and evaluation in an operational environment and for assessment of the supportability of the system. The tests should demonstrate that the proposed production system will meet its operational requirements and can be operated, maintained, and fully supported while in operational use.

In the Production phase, production of the equipment in appropriate quantities and deployment to field units with supporting equipment, repair parts, and documentation lead to the initial operating capability (IOC) to complete the formal development process and provide the final testing environment.

A major controlling document for every acquisition program is the TEMP, which lays out the overall schedule of development and operational test and evaluation. This test and evaluation process will verify that the new equipment does, in fact, meet the requirements. The specific content of the TEMP is described in greater detail in Section 13.9 and in DoD 5000.3-M-1 [2].

The T&E program is in some ways similar to the basic systems engineering process. Figure 13-4 illustrates some key relationships between the systems engineering process and T&E activities.

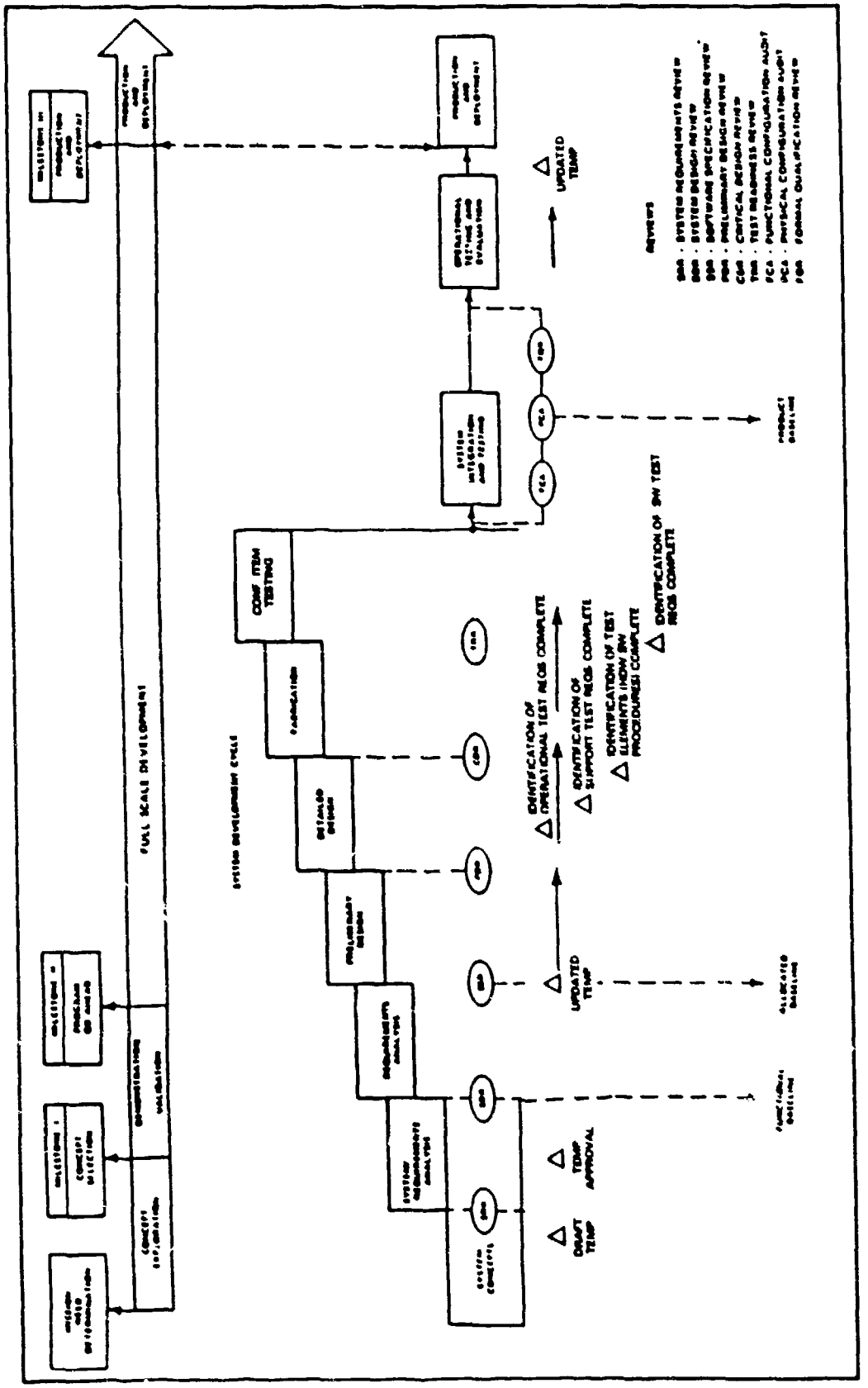
13.3.1 Concept Exploration/ Definition Phase Activity

Although the TEMP is not required in final form until the end of the C/E phase, draft sections of the TEMP may be prepared during C/E. As systems engineering information becomes available you can begin preparing Part I, Program Background, of the TEMP. Functional flow block diagrams (FFBDs), requirements allocation sheets (RASs), and test requirements sheets (TRSs) provide the principal supporting systems engineering documentation. During this phase, systems engineering documentation used in the trade study process provides the principal evaluation tools for selection among alternative concepts. If testing does take place, it is not likely to be on a prototype of the system, but more commonly on an experimental component that may be the heart of the development effort. Testing is limited in order to devote no more resources than necessary to tne process of selecting a concept. Sometimes C/E phase testing consists of adapting a currently fielded system to investigate its potential for another application. If test reports are developed, they are usually done by a technical agent or laboratory.

Some smaller programs have a less formal C/E phase where limited testing does take place. Sometimes the objective is not to select a concept, but more simply to demonstrate the feasibility of a known concept or technology alternative. This usually takes the form of "black box" testing at a laboratory, when a single performance attribute is in question.

At Milestone I, the PM should address alternative design concepts, alternative acquisition strategies, expected operational capabilities, industrial base capacity, readiness, support, personnel requirement projections, and cost estimates.

Figure 13-4
Relation of the Systems Engineering Process
to Key Test Activities



T&E planning at Milestone I should include an outline of the program and performance thresholds that are to be demonstrated during the D/V phase. Systems engineering documentation, such as the RAS and TRS, is the primary source for these thresholds. Thresholds are normally monitored through the technical performance measurement program (see Chapter 14 of this guide). Programs are required by DoDD 5000.3 [1] to have a TEMP at Milestone I.

For those programs where a Milestone I decision is not required, a TEMP is still required around the time that the milestone would have occurred -- the beginning of the first fiscal year containing program funding. For programs requiring a TEMP at Milestone I, the TEMP must be prepared during the C/E phase. At the latest, it should be developed, staffed, and approved prior to the conduct of any major OT&E events. Since the negotiation and approval process for TEMPs can be time consuming, it is strongly recommended that the Program Manager begin preparing the TEMP as early in the program as possible using the systems engineering documentation as a source of requirements. It is recognized that the initial versions of the TEMP will lack specifics, particularly in regard to test planning more than two years away. Nevertheless, this should not discourage early preparation using the level of systems engineering documentation available.

13.3.2 Concept Demonstration/ Validation Phase Activity

In the D/V phase, concepts that were generated during the C/E phase and selected for continuation are verified. This verification usually includes some hardware fabrication and demonstration. Program risks and uncertainties are identified, and some are resolved. Also during this phase, the system's allocated baseline configuration and other documentation necessary to enter the FSD phase are prepared based on the systems engineering process and documentation.

The scope of each program's D/V effort is primarily driven by the extent of new engineering development associated with the design. Generally, programs that use current technology have short D/V phases. The C/E and D/V phases can even be combined for such programs. In others, the design, fabrication, and testing of one or more advanced development models (ADMs) will be necessary.

The objectives of testing during the D/V phase are: 1) to verify that the areas of technical risk to be resolved during that phase are evaluated; 2) to assist in identifying the preferred technical approach to be taken during FSD; 3) to verify that the system has, at a minimum, the potential to be technically and operationally effective, as well as operationally suitable; and 4) to determine the T&E requirements to be achieved during FSD. To accomplish this, adequate DT must be conducted on each alternate system. If it is expected that the system will employ new operational concepts or involve significant operational risks, OT or an EOA may be conducted on the more promising systems, that is, those that meet most or all of the performance objectives. Sufficient OT is conducted to assess the operational effectiveness and suitability of each

recommended alternative.

DT and OT conducted on the candidate system components/ subsystems may evaluate such factors as producibility, compatibility, reliability, interoperability, electromagnetic environmental effects, logistics supportability, and maintainability. Normally these requirements will be identified using the RAS and TRS as primary systems engineering documentation. The preferred approach is selected through trade studies involving T&E results and other factors such as development, production, and life cycle costs.

At the FSD decision, Milestone II, the PM should be prepared to answer these T&E related questions:

a. Have the technical questions and critical issues posed at Milestone I been adequately resolved?

b. Has the T&E conducted been sufficient to reasonably ensure that the performance requirements can be achieved?

c. Have the technical questions and critical issues to be resolved prior to Milestone III been identified? Is the test program to resolve them adequately planned?

d. Have the technical and operational performance requirements and thresholds been refined? Have the provisions for demonstration of these requirements and thresholds been included in the updated TEMP?

13.3.3 Full Scale Development Phase Activity

The FSD phase encompasses the final engineering, prototyping, and testing necessary to demonstrate and document that the system is cost-effective, operationally effective, and operationally suitable. The final product is a baseline design for use during production.

For system acquisition programs with moderate to high technical risks, FSD often involves the fabrication and test of one or more engineering development models (EDMs) followed by the fabrication and test of one or more LRIP models. For programs of lesser risk, it may involve pilot production models only.

When the design is validated sufficiently, pre-production models are manufactured to approximate the final intended production configuration as closely as possible. Usually, the number of units is limited to the amount needed to conduct FSD testing. Occasionally, a larger number may be authorized for a variety of reasons, such as the urgent need to provide an early deployment, the need to resolve an existing producibility risk prior to Milestone III, or the need to minimize very uneconomical stand-down periods for production facilities and personnel. In any of these cases, however, the risk of concurrently manufacturing the additional units while final FSD testing is taking place must be sufficiently low to warrant the increased financial investment.

DT of LRIP models is performed to verify the effectiveness of improvements made as a result of T&E on the EDMs, verify the achievement of required technical performance

specifications, and identify any improvements to be incorporated into the production version. The final phase of DT for the LRIP models is technical evaluation conducted in a representative operational environment to evaluate readiness for OT. OT is conducted on LRIP models to assess the operational effectiveness and operational suitability of the system. The final phase of OT during FSD is operational test and evaluation conducted in a realistic operational environment. OT is usually conducted on the same hardware as DT.

13.3.4 Production and Deployment Phase Activity

The transition from FSD to Production translates the engineering model into production hardware for delivery to the user. The objectives of the production effort are to achieve: 1) production of authorized quantities on schedule and within budget; and 2) readiness for system deployment. The objectives of the deployment effort are to achieve a high level of operational readiness for the deployed system, that is, personnel assignment, training, maintenance, supply/spare support and overhaul, alteration, and repair. The Production and Deployment Decision (Milestone III) is the decision to produce systems for permanent installation on fielded units, land-based configuration, and training facilities, or for inventory. The production phase entails (as required) both development and operational testing. Activity is focused on production qualification testing of production items. Additional limited development test and evaluation is conducted after Milestone III, usually to:

a. Verify the effectiveness of product improvements or corrections made after the FSD technical and operational testing.

b. Demonstrate the adequacy of redesigns as a result of production problems or early follow-on operational test and evaluation.

Effective data collection and analysis are essential components of a successful T&E program. Assessment and evaluation of a system are continuing efforts throughout production and deployment. Future T&E efforts depend heavily on lessons learned from previous procurements, and ways to improve performance must continually be sought. Thus, an effective T&E program must incorporate continuing evaluation of a newly procured system while it is deployed in its operational environment.

Successful ongoing assessment requires a means to identify, report, and analyze the cause of all failures and provide for appropriate corrective action such as design changes, manufacturing process changes, and improved quality control.

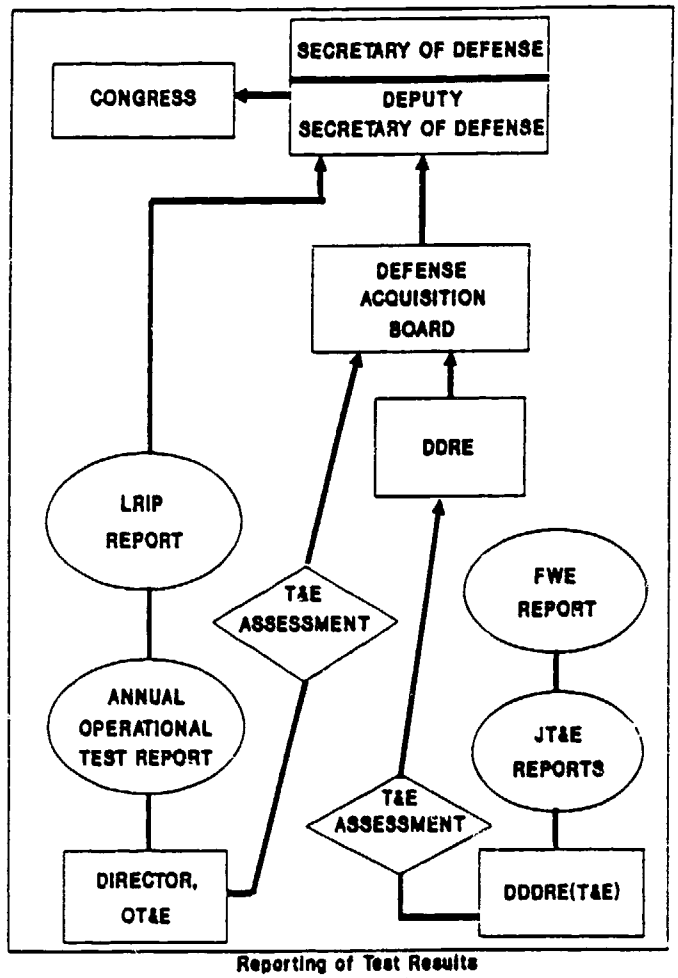
Reliability assessment is primarily concerned with problem identification and evaluations to assess operational performance. Data should be collected on all technical problems and failures, which should be classified as critical, major, and minor; failures should also be evaluated as relevant or non-relevant. Relevant failures are defined as failures in the system being tested; other failures are considered non-relevant (e. g., if the test equipment breaks during testing). Relevant failures require retesting, whereas

testing can continue after repair of a non-relevant failure. Finally, careful management of data generated through corrective activities is essential.

13.4 MANAGEMENT OF TEST PROGRAMS

The PM, through the systems engineer, must coordinate testing conducted by contractors, subcontractors, laboratories, and field activities, and must maintain a real-time network that provides all the proper information with which to make engineering and program decisions. The TEMP can be an effective tool to document this network, to publicize the reporting procedures, and to identify contingency plans and resources.

Regardless of the size of the program office staff, someone should be directly responsible for focusing appropriate management attention on the T&E program, and that individual's name should be publicized as a point of contact. Experience has shown that the first critical task, and the one that should remain prominent as the program progresses, is to identify and assemble the necessary T&E engineering support at each of the locations of major program activity. The requirements will vary



Reporting of Test Results
Figure 13-5

as the program passes through the different phases. Keeping a good balance of such support and maintaining well-defined working relationships requires significant program office attention, frequently more than anticipated.

13.5 TEST PROGRAM REPORTING

A graphic summary of test reporting paths is shown in Figure 13-5. As described in DoDD 5000.3 [1], these formal T&E reporting requirements prepared by major T&E agencies include the following for the Director, OT&E.

a. DOT&E ASSESSMENT - Prepared for each formal review of a major system under development, this assessment is a report of the operational effectiveness and suitability of the system, based on the results of operational testing.

b. LRIP Report - Prepared for the Secretary of Defense and Congress, this report addresses whether OT&E on initial production items was adequate, and whether results confirm the effectiveness and suitability of the items.

c. Annual OT&E Report - Submitted to Congress, this report summarizes all OT activities within DoD for the fiscal year, including recommendations on the status and adequacy of OT resources and funding levels.

For the DDDRE(T&E) formal T&E reporting requirements include:

a. Defense Acquisition Board (DAB) Assessment - Provided at each formal system review, this report contains a detailed technical assessment of the system's performance.

b. Annual Foreign Weapons Evaluation Report - This is an annual report to Congress on NATO systems/ equipment evaluated during the previous fiscal year.

c. Joint Test and Evaluation Program Reports.

DoD components are responsible for providing documentation including end-of-phase test reports (both DT and OT), reports of significant T&E events (such as missile launches or live firings), annual OT reports, T&E financial reports, and information for congressional data sheets and contract award reports.

The PM must support the needs of these and other formal reporting requirements. In addition, detailed test reports must be available to substantiate the conclusions and recommendations of the PM.

At every level of the organization, there are many incentives to minimize formal written reporting. It is expensive and time-consuming, and its full value is rarely understood by the developer of the report. But written reporting is an absolute necessity as a vital communication medium among the organizations involved in the program and among the echelons within each organization. Test reports are also important historical documents. Frequently, reports from earlier test events are recalled during development of engineering changes to the system.

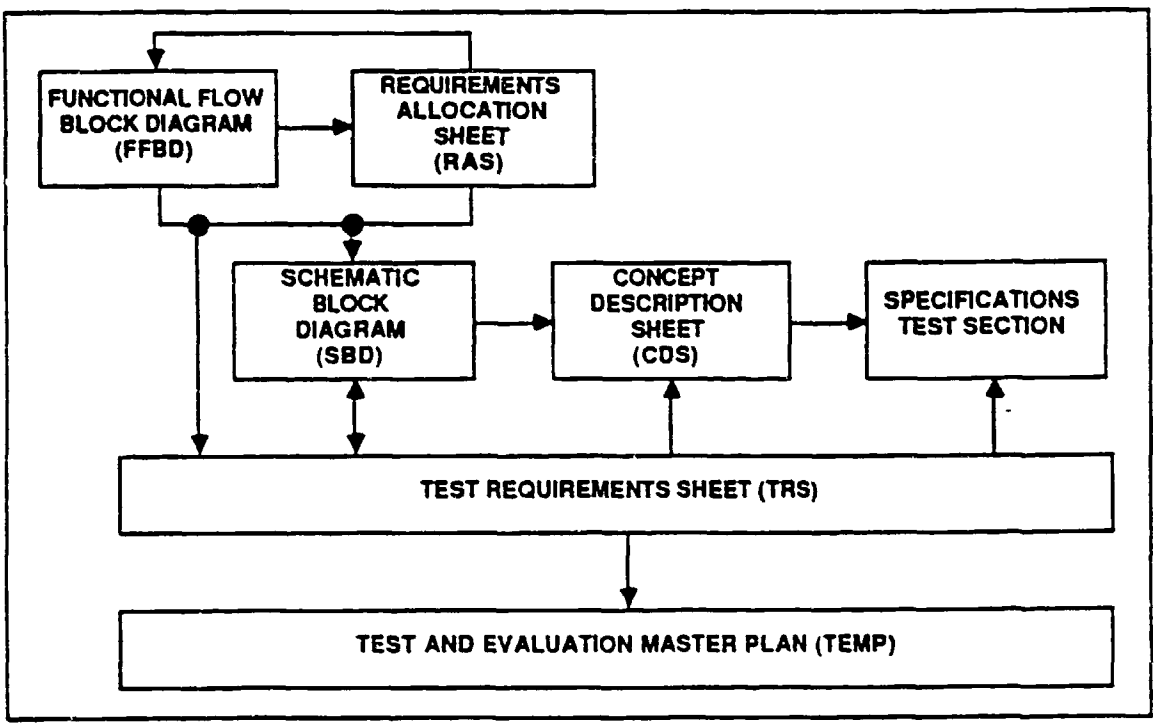
13.6 RELATION OF T&E TO SYSTEMS ENGINEERING DOCUMENTATION

The role of the systems engineering process and its related documentation is fully described in Chapters 6, 7, and 8 of this guide. The identification of test requirements is an integral part of the systems engineering process. Test requirements primarily appear on RASs, Concept Description Sheets (CDSs), and TRSs. Testing requirements also surface in the WBS, statement of work, the system specification, and the Integrated Logistics Support Plan (ILSP)/ Logistics Support Analysis (LSA) documents. The TRS is the principal test requirements document and provides a primary input to the TEMP as well as the test requirements section of specifications of all types. The TRS is described in detail in paragraph 13.9. The flow of test requirements in the principal systems engineering documentation is shown in Figure 13-6.

13.7 RELATION OF T&E TO THE TECHNICAL PERFORMANCE MEASUREMENT PROGRAM

The technical performance measurement (TPM) program, described in Chapter 14 of this guide, must be considered as an integral part of the T&E program. TPM is defined as product design assessment and forms the backbone of the development testing program. It estimates, through engineering analyses and tests, the values of essential performance parameters of the current design and serves as a major input in the overall evaluation of operational effectiveness and suitability.

Figure 13-6
Flow of Test Requirements in Primary Systems Engineering Documentation



13.8 RELATION OF T&E TO THE SOFTWARE DEVELOPMENT PROCESS

Chapter 20 of this guide describes the specialized role of test and evaluation in the software development process. Because of unique demands imposed by software, special procedures, documentation, and design reviews are set out for test and evaluation of software. For clarity, this material has not been repeated in this chapter. However, it should be considered an integral, vital part of the overall T&E program.

13.9 DOCUMENTATION

13.9.1 Test and Evaluation Master Plan

The Test and Evaluation Master Plan (TEMP) is in a five part format as detailed in DoD 5000.3-M-1 [2]. Briefly, Part I concerns system details including production delivery information and the operational and technical goals and thresholds. Part II, program summary, includes a schedule chart that provides an overview of the major acquisition and T&E events. Parts III (DT Outline) and IV (OT Outline) describe in quantitative terms the scope of each major test period. Part V, the Test Resource Summary, identifies special resources required for the test program and when those resources will be needed. The format must be adhered to as closely as possible, to assist the many organizations that utilize the TEMP as a source of selected information for their planning, resource allocation, and facilities management. The specified format is shown in Figure 13-7.

The TEMP is a dynamic document with contents that should be factual and specific, avoiding generalities and emphasizing quantifiable and testable requirements, both operational and technical. Although a summary document, it is imperative that pertinent, but integrated, facts and descriptions be included. The contents must describe the amount and type of testing to be conducted before each milestone, and the resources required. The PM is responsible for developing the TEMP, including its content and preparation. However, since Part IV concerns operational T&E, DoD components usually require the Operational Test Agency to be responsible for the preparation, content, and coordination of that part of the TEMP. Therefore, the PM must establish early liaison with the OTA to ensure an integrated approach to the TEMP.

Part I - System Details

Part I contains the mission and system descriptions; the system objective in terms of mission or operational requirements; and the statement of operational and technical goals and thresholds.

The system description is a brief, mission-oriented statement describing the new or improved capability that this system is intended to provide. It must be traceable to systems engineering documentation such as the FFBD and RAS. While it must be concise, the system description is written with the assumption that most TEMP readers lack extensive familiarity with the program. Key functions and interfaces with other systems must be described. Again, this material must be correlated with the systems engineering documentation and the system level

Typical TEMP Format
Figure 13-7

Part I- System Description

1. Mission Description
2. System Description
3. Required Technical Characteristics
4. Required Operational Characteristics

Part II- Program Summary

1. Management
2. Integrated Schedule

Part III- DT&E Outline

1. Critical Technical Characteristics
2. DT&E to Date
3. Special Requirements for System/ Subsystem Retest
4. Future DT&E

Part IV- OT&E Outline

1. Critical Operational Issues
2. OT&E to Date
3. Future OT&E

Part V- Test and Evaluation Resource Summary

1. Test Articles
2. Test Sites and Instrumentation
3. Test Support Equipment
4. Threat Systems
5. Test Targets
6. Operational Force Test Support
7. Simulators, Models, and Testbeds
8. Special Requirements
9. T&E Funding Requirements
10. Resource Schedule
11. Manpowwer/ Training

Appendices

specification (Type A specification). If the system appears to be similar to systems currently in service, this paragraph should indicate the ways that it differs. Part I must relate directly to the mission need statement (MNS), acquisition strategy, systems engineering data package, and the ILSP. Each of these documents contains data that augment the planned system operational concept.

Part I contains an abbreviated, functional system description including the key functions of the system, the inter-\ and intra-system interfaces, as well as unique system characteristics. When practical, key functions should include a mission/ function matrix showing the relation between primary functional capabilities that must be demonstrated through testing of the operational mission(s) and concept(s). Part I must include statements concerning unique characteristics that could lead to special test requirements such as nuclear hardness, data-link vulnerability, and electromagnetic emission control. The remaining Part I elements are performance oriented characteristics and issues. Each paragraph should contain information on characteristics that must be achieved to avoid jeopardizing program viability or success. In most cases, these items should include reliability, availability, and maintainability as identified in the decision milestone documentation.

The required characteristics are those areas of technical and operational risk that must be resolved by test and evaluation and that are critical to the success of the program. For major acquisition programs, they can be derived from the System Concept Paper (SCP), Decision Coordinating Paper (DCP) or other decision process documentation. In addition to identifying required characteristics, the specific test events in Parts III and IV that address each issue should be cross-referenced. Issues resolved through test and evaluation are dropped from Part I and discussed under results of tests to date in Part III and IV, as appropriate. If and when new issues surface, they should be added to Part I.

Operational and technical thresholds include specific performance requirements. As stated in this section, these are the requirements against which the system ultimately will be evaluated. It is important that these thresholds be traceable through the systems engineering documentation and correlated to the TPM program. Thresholds are the minimum acceptable value, consistent with the operational requirements, that must be demonstrated for program approval and continuation. To the extent that these requirements are loosely defined, the operational evaluation will also, of necessity, be subjective. If test planning is poorly done, the PM and the operational test director could have different views about the expected system performance and capability. The PM and the OTA must develop quantifiable, testable thresholds and include them in the TEMP. The thresholds that are of major concern (the most demanding) must be included.

In some cases, there can be overlap between the development test and operational test thresholds. In general, an operational test threshold reflects what the unit with the equipment or system will do, while the development test threshold reflects how well the equipment or system will perform the task.

Failure criteria for the reliability thresholds must be delineated and agreed upon by both the PM and operational test director. The failure criteria identify what is counted as a failure, as well as the classification of failures as critical mission preventing, major mission degrading, or minor failures. If the configuration of the system involves software, these criteria can be equated to software failure.

Part II - Program Summary

Part II, management is addressed to identifying responsible T&E organizations in conjunction with the T&E strategy needed to support the overall program acquisition strategy. Define quantities of production articles (LRIP) necessary to support T&E. Discuss constraints on schedule, budget or other resources which may impact T&E activities.

Part II, the integrated schedule chart, can be a one-page chart indicating the major development test and operational test periods and their relationship to the decision milestone, test article availability, and production deliveries. Most errors that appear in this chart are the result of either missing information or faulty sequencing (such as a test beginning before test articles are available, test reports due before completion of tests, or a milestone decision shown prior to the schedule completion of the test that provided the results to support the decision). Undue optimism frequently leads to a milestone decision shown concurrent with the completion of testing. The schedule should reflect a realistic sequence of events with adequate time to allow for document preparation and the necessary review cycles.

Part III - DT&E Outline

Part III, the DT outline, includes a description of each major DT period, stating briefly the configuration of the system being tested, the objective of the test period, and the scope of the testing. For the sake of brevity, a description of past T&E periods may be combined and need not emphasize quantifications in the scope of testing. However, the objectives achieved and summary conclusions drawn should be included. Part III also discusses scheduled pre-production qualification test and evaluation, production qualification test and evaluation, and any requirements for system or subsystem retest.

Part IV - OT&E Outline

Part IV, the operational test outline, is usually provided by the OTA evaluator. In some cases, particularly during the D/V phase and early in the FSD phase, demonstration of selected test requirements might be met by concurrent development and operational testing, or combined development and operational testing. Concurrent or combined testing is considered where the use of development test results in operational testing reduces total test time and cost. Such a strategy must be agreed to in advance by both the Program Manager and the operational evaluator and must be documented in this part of the TEMP as well as in the acquisition strategy. In any case, close coordination with the program managers test director and the OTA will be necessary to ensure adequate integration of the operational test phase with the remainder of the test program, and with

the rest of the TEMP.

Part V - Test and Evaluation Resource Summary

Part V, the T&E resource summary, is often neglected. Essentially, this part identifies special resources and facilities needed to execute the T&E program. The entries in this summary should reflect, where applicable, resources such as type of aircraft, number of flight hours required, class of ship, battlefield threat simulators, and threat aircraft required for operational realism. Part V identifies the quantities, types, and configurations of test articles, the major ground-based test sites, climatic laboratories, special gunnery ranges, or unusual/special real estate considerations. This part of the TEMP should include any special equipment installation and removal schedules, and personnel training and travel requirements. The systems engineering process should be used to define these requirements.

The two most common errors in preparing the Test Resource Summary are omissions and inconsistencies. Omissions commonly include ammunition requirements that are above and beyond the requirements for training. Ammunition typically can require 30 or more months to obtain. Inconsistencies include test period differences due to poor and inadequate schedule control. Planning for the use of ranges, test facilities, and targets should be included in this part. The capabilities of frequently used facilities should be consulted. Readily available documents include information concerning the commonly used aerial, surface, and subsurface targets, as well as data collection, storage, and reduction requirements.

13.9.2 Test Requirements Sheet

The Test Requirement Sheet (TRS), shown in Figure 13-8, an Army-peculiar document, is an example of a worksheet that serves several purposes in the systems engineering process. It identifies all the requirements that must be demonstrated or verified during the life cycle testing. The TRS serves as a tool for management to check whether appropriate provisions have been made for verification of all performance/ design requirements. It also provides for the identification of test functions for the test cycle of the systems engineering process. The TRS is used to describe test requirements of the overall system. By appropriate repetition, the TRS is indentured to the level desired (e.g., end item. assembly, sub-assembly, or component).

The TRS for a system, item, or assembly contains information referencing each test requirement from the system, development, or product (Types A, B, and C respectively) specifications that is subject to verification. It also identifies the verification method and the type of testing (as discussed in paragraph 13.3).

For each system, end item, assembly, subassembly, or component for which the verification method is designated in column 2, functional analysis (using RAS, FFBDs, and TLS), synthesis (using Schematic Block Diagrams (SBDs) and Concept Description Sheets (CDSs), evaluation and decision (using Trade Study Reports (TSR)), and description (using Design Sheets (DS)) are required in order to ensure the timely availability of the

TEST REQUIREMENT SHEET	NOMENCLATURE	CI NO. DETAIL SPEC. NO. (OR OTHER IDENTIFICATION)

METHOD LEGEND

NA NOT APPLICABLE 1. EXAMINATION 2. REVIEW OF ANALYTICAL DATA 3. DEMONSTRATION 4. TEST

TEST TYPE LEGEND

COORDINATED TEST PROGRAM (AR 70-10)

- A. ENGINEERING DESIGN TEST
- B. DEVELOPMENT TEST I
- C. OPERATIONAL TEST I
- D. DEVELOPMENT TEST II
- E. OPERATIONAL TEST II
- F. DEVELOPMENT TEST III
- G. OPERATIONAL TEST III
- H. PRODUCT IMPROVEMENT PROPOSAL TEST
- I. TECHNICAL FEASIBILITY TEST

PRODUCTION & POST-PRODUCTION TESTING (AR 702-9 / AR 702-10)

- J. FIRST ARTICLES TESTING
- K. COMPARISON TEST
- L. QUALITY CONFORM. ACCEPT. INSP.
- M. INTERCHANGEABILITY TEST
- N. RECONDITIONING
- O. INT. MAINTENANCE SHOP TEST
- P. SURVEILLANCE TEST

USER TEST (AR 71-3)

- Q. FORCE DEVELOPMENT TEST AND EXPERIMENTATION
- R. OPERATIONAL FEASIBILITY TEST
- S. ON-SITE USER TEST

REQUIREMENT REFERENCE PER SECTION 3 OF SPECS	VERIFICATION METHOD					COORDINATED TEST PROGRAM									PROD AND POST PROD							USER TEST			VERIFICATION REQUIREMENTS PER SECTION 4 OF OF SPECIFICATION(S)
	NA	1	2	3	4	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	

CONTINUATION SHEETS AS REQUIRED

Figure 13-8
Test Requirements Sheet

test elements. Test elements stated in the specifications are the source of performance requirements for test functions. Test equipment, facilities, personnel, computer software, and procedural data to satisfy these requirements are derived from the test cycle of systems engineering.

13.10 REFERENCES

1. DoDD 5000.3, "Test and Evaluation".

2. DoD 5000.3-M-1, "Test and Evaluation Master Plan Guidelines".

3. DoD 5000.3-M-2, "The Department of Defense Foreign Weapons Evaluation and NATO Comparative Test Programs".

4. DoD 5000.3-M-3, "Software Test and Evaluation Manual".

5. DoD 5000.3-M-4, "Joint Test and Evaluation Procedures Manual".

6. DoD 5000.3-M-5, "Planning Development Test and Evaluation for Operational Relevance".

7. DoDD 5000.1, "Major and Non-Major Defense Acquisitions Programs".

8. DoDI 5000.2, "Defense Acquisition Program Procedures".

9. DoDD 5141.2, "Director of Operational Test and Evaluation".

10. AR 70-10, "Test and Evaluation During Development and Acquisition of Material".

11. AR 71-3, "User Testing".

12. AFR 80-14, "Test and Evaluation".

13. OPNAVINST 3960.10C, "Test and Evaluation".

14. MCO 5000.11A, "Testing and Evaluation of Systems and Equipment for Marine Corps".

15. MIL-Q-9858A, "Quality Program Requirements".

16. DSMC, "Test and Evaluation Management Guide", March 1988.

CHAPTER 14

TECHNICAL PERFORMANCE MEASUREMENT

14.1 INTRODUCTION

The Program Manager (PM) must be cognizant of three basic program elements: 1) cost, 2) schedule, and 3) technical performance. The first two are tracked through cost and schedule control systems. The last item is tracked through the technical performance measurement (TPM) system defined in MIL-STD-499A [1].

TPM is defined as the product design assessment which estimates, through engineering analyses and tests, the values of essential performance parameters of the current design of work breakdown structure (WBS) product elements. TPM is used to 1) forecast the values to be achieved through the planned technical program effort, 2) measure differences between the achieved values and those allocated to the product element by the systems engineering process, and 3) determine the impact of these differences on system effectiveness. The purpose of TPM is to:

a. Provide visibility of actual versus planned performance

b. Provide early detection or prediction of problems which require management attention

c. Support assessment of the program impact of proposed change alternatives.

Use of TPM alerts program management to potential performance deficiencies before irrevocable cost or schedule impact occurs. Where a program also has an overall risk assessment program, TPM provides data for technical risk planning and assessment. Input from the risk management process will also assist in determining parameter criticality in the TPM selection process.

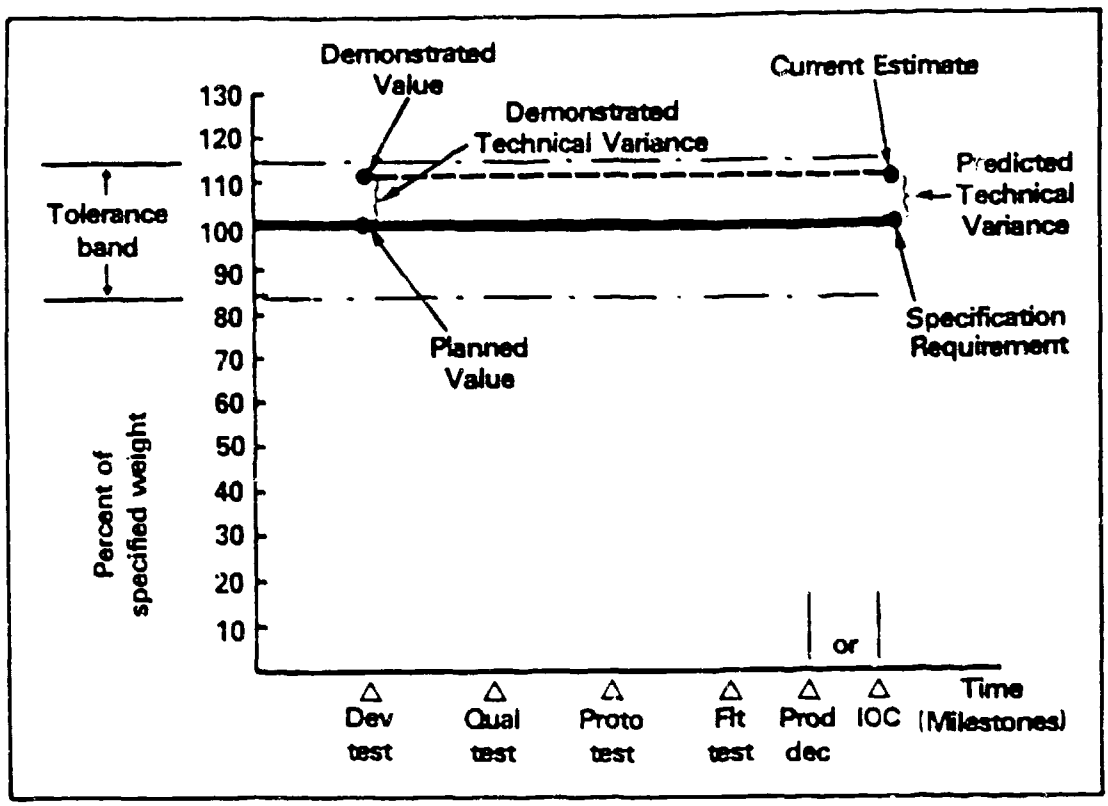
TPM takes selected critical product elements of the contract work breakdown structure (CWBS) and provides a method of monitoring their technical status throughout the program. In implementing TPM, values of measurement, illustrated in Figure 14-1, are defined as follows:

a. Planned Value - The anticipated value of a parameter at a given point in the development cycle. A plot of planned value versus time is known as the planned value profile. It may be desirable to indicate a range of acceptable values versus time. When this range is shown, it is known as a tolerance band.

b. Demonstrated Value - The value estimated or measured in a particular test or analysis.

c. Specification Requirement - The value or range of values contained in a contractual development specifications (Type B) or

Figure 14-1
TPM Definitions



allocated from such a specification, with a verification requirement for the end product.

d. Current Estimate - The value of a parameter predicted for the end product of the contract.

e. Demonstrated Technical Variance - The difference between the planned value and the demonstrated value of a parameter.

f. Predicted Technical Variance - The difference between the specification requirement and the current estimate of the parameter.

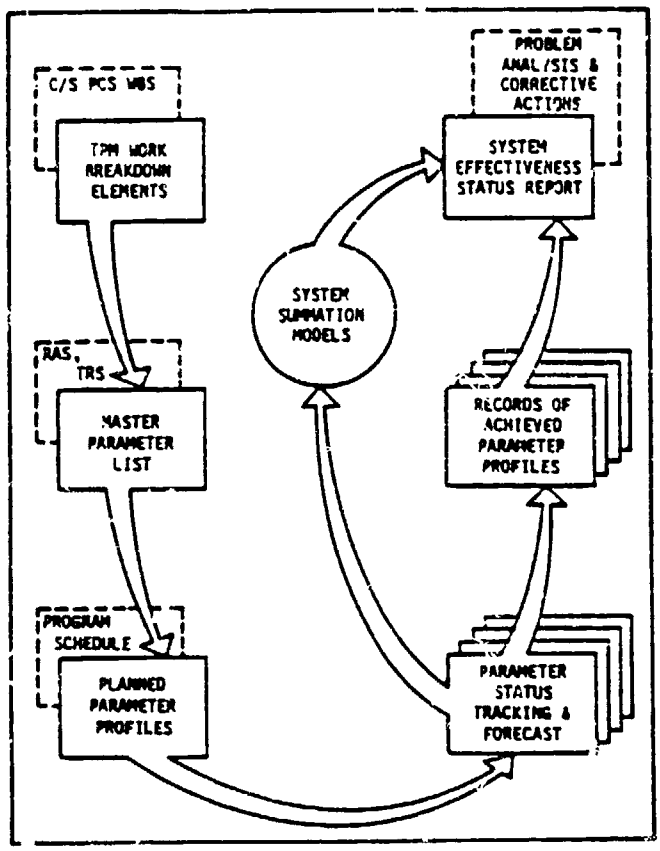
Technical parameters to be reported and tracked are determined through identification of technically critical areas from review of systems engineering documentation, development specification (Type B) requirements, and planned contractual performance incentives and their relationship to system measures of effectiveness. Parameters to be tracked by the contractor should be identified in the contract. At the completion of each evaluation, results are recorded for comparison with planned values. Variances in results from planned values are analyzed. The analysis includes evaluation of the effect of variances on the technical program risk, schedule, and cost. Summary performance status reports are prepared from the basic parameter status data

provided by TPM. The information flow for assessment is illustrated in Figure 14-2. It includes TPM work breakdown elements, master parameter list, planned parameter profiles, summation models, parameter status tracking and forecast, records of achieved parameter profiles, summary performance status report, and problem analysis and corrective action. The first four items are the outputs of planning and replanning efforts. They form the inputs to technical performance measurements and assessments. These four items can be initially accomplished during the Concept Demonstration/ Validation (D/V) phase of the program.

14.2 PLANNING FOR TPM

During the preparation of the D/V phase requests for proposal (RFPs), the program office must ensure that a requirement for a TPM program is specified. Normally a TPM program is initiated through a requirement for an Assessment Plan as part of the System Engineering Management Plan (SEMP). The Assessment Plan identifies the parameter selection process and parameters that have been selected at the time of plan submittal. To the extent parameters have been identified, the plan forecasts the values to be attained through the development program and the methods to be used for assessing and

Figure 14-2
TPM and System Effectiveness
Assessment Information Flow



forecasting. For each scheduled assessment, the plan specifies the conditions associated with conducting tests or other evaluations, and the measurement methodology. In summary, a typical Assessment Plan contains the following information:

a. A summary of the plan for demonstration of system technical performance

b. Lists of all critical configuration items (CIs), their work breakdown structure (WBS) numbers, and specification numbers; the key parameters for each CI; and numbers of specification paragraphs which completely identify these key parameters and their quantitative requirements

c. Lists of milestones related to performance achievement for the system and each subsystem by titles and schedule milestone numbers

d. Lists of the numbers of Test Information Sheets for those performance achievement events (PAEs) that are tests.

TPM can begin when configuration item requirements allocation is substantially complete (when draft Type B specifications are available). Normally this would happen during the D/V phase. A good key for timing the initiation of a TPM effort would also be when the majority of configuration item Preliminary Design Reviews (PDRs) have been completed. It is only at this point that a reliable and stable allocated performance base for WBS product elements is available. A TPM program continues until testing has proven that design is complete. TPM is extended into the Production phase whenever there are major modification or product improvement programs involving CI design changes.

If product design is not stable during D/V, TPM planning may start, but initiation of assessment and reporting could be postponed until the early part of Full Scale Development (FSD). Another option is to begin only on stable parts of the WBS and withhold implementation on selected elements that may be more unstable. However, in most cases this is not desirable since it does not provide valid system level reporting.

14.3 SELECTING TPM PARAMETERS

The selection of parameters for TPM begins with a review of contract performance incentives, performance specifications, and/or systems engineering documentation that details critical performance elements. Ordinarily, a review of the relationship of these elements to system measures of effectiveness will be necessary to identify or confirm parameter criticality. Parameters selected for tracking should be key indicators of program success. In developing a cost-effective TPM program, only a few key parameters should be selected at the top level because the total number of detailed parameters tracked to support these key parameters may be 10 times greater. Parameters can be related to hardware, software, logistics, human factors, that is, to any product or functional area of this system. Typical TPM parameters include those listed in Figure 14-3. Because an increasing amount of system development resources are related to software development, and because software often poses the greatest technical

Figure 14-3
Typical TPM Parameters

- Weight
- Power
- Computer Throughput
- Computer Memory Size
- Command Allocations
- Telemetry Allocations
- Cooling Capacity
- Target Location Accuracy (Circular Error Probability)
- Operators and Maintenance Personnel Required
- Volume/Area (Air/Sea Lift)
- Reaction Time/Responsiveness
- Receiver Signal Sensitivity
- Ranging Accuracy
- Data Link Anti-Jam Margin
- Reliability/Maintainability/Availability
- Range
- Survivability Measures (e.g., Nuclear Hardness and Damage Tolerance)
- Coverage Area/Volume
- Processing Time
- Payload (Weight and Volume)
- Communications Capacity (Bandwidth, Number of Links)

risk, PMs should be particularly sensitive to the selection of parameters from this area. The parameters selected should be limited by the following criteria:

a. They are the most significant qualifiers or determinants of the total system product.

b. A direct measure of value can be rapidly derived from results of analyses or tests.

c. Time-phased values and tolerance bands can be predicted for each parameter and substantiated during design, development, and test.

The framework for a TPM parameter tree is developed from the CWBS, described in Chapter 9 of this guide. The CWBS defines all tasks to be accomplished on the program and follows the system hierarchy and program specification tree. Principally, the product elements of the CWBS are applicable to TPM. Some items, such as support equipment, may not contribute significantly to the selected TPM parameters. However, some elements may contribute to several parameters, for example, weight, power, reliability, and error from a guidance component.

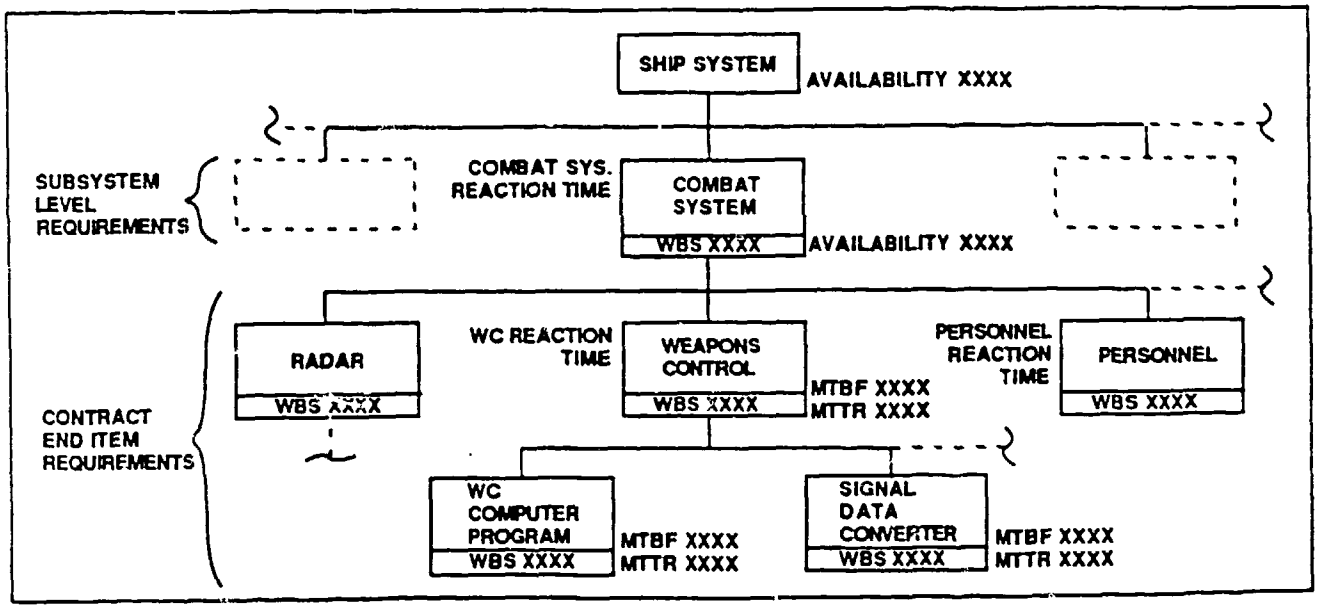
The TPM parameter tree defines the build-up of system parameter summaries from selected elements of the CWBS. Where selected parameters share a common WBS element, a single tree can define the TPM schema. Where differences cannot be easily shown by coding, more than one tree may be required for the overall program.

The linkage between the CWBS and the TPM parameter tree is the key to the parameter tree's use as an effective management tool. Developing the TPM parameter tree from the CWBS ensures traceability of progress on technical performance to cost and schedule aspects of the work effort (through the cost/ schedule control system). Program management can then associate technical performance variances (such as a weight parameter exceeding the tolerance limit by 10 percent) with schedule and budgetary status (80 percent of budget expended, less than one month for final value to be achieved).

Note that the TPM parameter tree may not perfectly correspond to the CWBS in content or degree of detail. For example, in solving a complex software problem, it may be necessary to expand certain parts of the WBS to facilitate parameter tracking in that area.

Figure 14-4 illustrates a partial tree for a shipboard combat system electronic suite. It illustrates how requirements can be tracked at several levels. In the example, availability requirements are set and tracked at the ship and combat system level. However, these summaries are products of mean time between failures and mean time to repair (MTBF and MTTR) requirements set by the specification for the weapons control package. Requirements for MTBF and MTTR are set by requirements imposed on configuration items such as the weapons control computer program or signal data converter. During the planning phase, one or all of these levels could be chosen for tracking, depending on the criticality, and perhaps the inherent technical risk, of the parameter. The other parameter listed,

Figure 14-4
TPM Parameter Tree



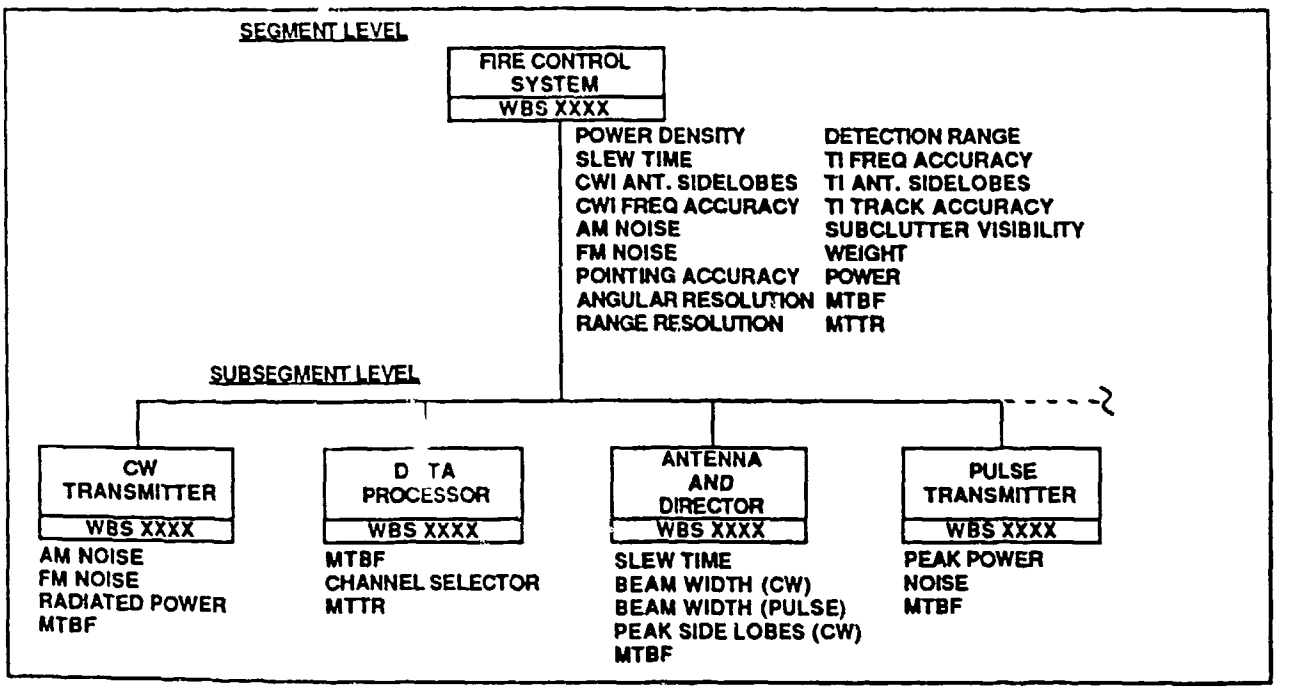
combat system reaction time, is perhaps the product of weapons control reaction time, personnel reaction time, etc. It may not be necessary to establish TPM targets below this level. In all cases, the TPM parameter tree or trees must be correlated to WBS elements. Figure 14-5 provides a TPM tree for a fire control system.

The lower level parameters are identified through the requirements allocation process. These parameters represent allocation of system level requirements to lower levels within the system hierarchy and should be available in the documentation of the functional analysis process (refer to Chapter 6 of this guide).

The identification of parameters and the parameter Assessment Plan is closely related to the system synthesis described in Chapter 7 of this guide. This is the point where end item requirements allocation sheets (RASs) are developed and end item test requirements sheets (TRSs) are generated. The data are then compiled into the end item (product) specifications (Type C).

Key TPM parameters must be selected using the full scope of the systems engineering process. A comprehensive set of key parameters should be selected for the system, for each segment, for and for each critical CI, on the basis of overall technical importance, technical risk assessment, parametric sensitivity in the engineering models, and interface relationships. Top summary level parameters and their quantitative requirements will normally become part of the development

Figure 14-5
Shipboard Fire Control System TPM Parameters (Partial)



specifications (Type B).

Each TPM program should establish the requirement for a controlled Master Parameter List. The Master Parameter List is usually developed by competing contractors during the D/V phase and contains all technical parameters that have been selected for measurement as part of the TPM program. Where the program office has certain specific technical parameter reporting needs, the D/V phase RFP could contain a partial list of parameters to be included in the program. The RFP may also identify the WBS level where assessment should take place. Figures 14-6 and 14-7 illustrate Master Parameter Lists for an aircraft and its engine subsystem.

14.4 DEVELOPING PLANNED PROFILES

For each selected performance parameter, a planned performance profile must be established. As one of the initial steps of a TPM program, each design group will prepare appropriate profiles using historical data, test planning, contract requirements, etc. For those parameters that will be reported to the program office, planned profiles are reviewed and approved by the organization establishing the need for that data.

Planned profiles may reflect constant values. This would probably be associated with technically mature, low risk contract end items. In this case, the profile would appear

Figure 14-6
TPM Parameters - Aircraft

MAXIMUM TAXI DESIGN WEIGHT	INFRARED EMISSION
WEIGHT EMPTY	RADAR CROSS-SECTION
MAXIMUM FLIGHT DESIGN WEIGHT	SINGULARLY VULNERABLE COMPONENTS
PAYLOAD, INTERNAL	NUCLEAR THERMAL LOAD
PAYLOAD, EXTERNAL	REACTION TIME, CREW IN COCKPIT
RANGE, BASIC MISSION	TURNAROUND TIME
SUSTAINED SPEED AT HIGH ALTITUDE	AIR VEHICLE MAINTAINABILITY
SUSTAINED SPEED AT LOW ALTITUDE	AIR VEHICLE MISSION RELIABILITY, BASIC MISSION
PENETRATION SPEED, BASIC MISSION	LOW-LEVEL ALTITUDE
TAKEOFF DISTANCE, STANDARD DAY	RIDE QUALITY, VERTICAL
TAKEOFF DISTANCE, HOT DAY	RIDE QUALITY, LATERAL
LANDING DISTANCE, STANDARD DAY	USEFUL LIFE
EXCESS THRUST AT MAXIMUM FLIGHT DESIGN WEIGHT	ESCAPE SYSTEM PERFORMANCE, CREW SAFETY

Figure 14-7
TPM Parameters - Aircraft Engine Subsystem

MAXIMUM THRUST SEA-LEVEL STANDARD (LBS)
INTERMEDIATE THRUST SEA-LEVEL STANDARD (LBS)
INTERMEDIATE THRUST AT B-1 REFUEL (LBS)
SPECIFIC FUEL CONSUMPTION AT B-1 SUPERSONIC CRUISE (LB/HR/LB)
SM REQ'D/SM AVAIL. (STATIC MARGIN)
TOTAL ENGINE WEIGHT (LBS)
RELIABILITY - MTBPL (HR) (MEAN-TIME-BETWEEN-POWER-LOSS)
MAINTENANCE MAN-HOUR RATE (MAN-HOURS/EFFECTIVE FLYING HOURS)

as a horizontal line against time. This type of profile is illustrated in Figure 14-8(a). The requirement is the same at each major milestone for this end item -- that is, ***"demonstrate that you have not exceeded the specification weight."***

Establishing realistic profiles is not usually this simple. Most development items are not expected to reflect mature values during initial analysis and testing. Figure 14-8(b) illustrates that, historically, in the development of similar components, necessary design changes have led to growth of approximately 15 percent in weight. The profile in Figure 14-8(b) compensates for this growth by making the initial requirement more stringent. Figure 14-8(c) illustrates perhaps another variation of this case where, because of a planned weight reduction program, the initial unit is expected to be heavier than the production item.

Planned profiles should not be viewed as static, particularly where systems engineering/engineering development is still

Figure 14-8
Planned Parameter Profiles

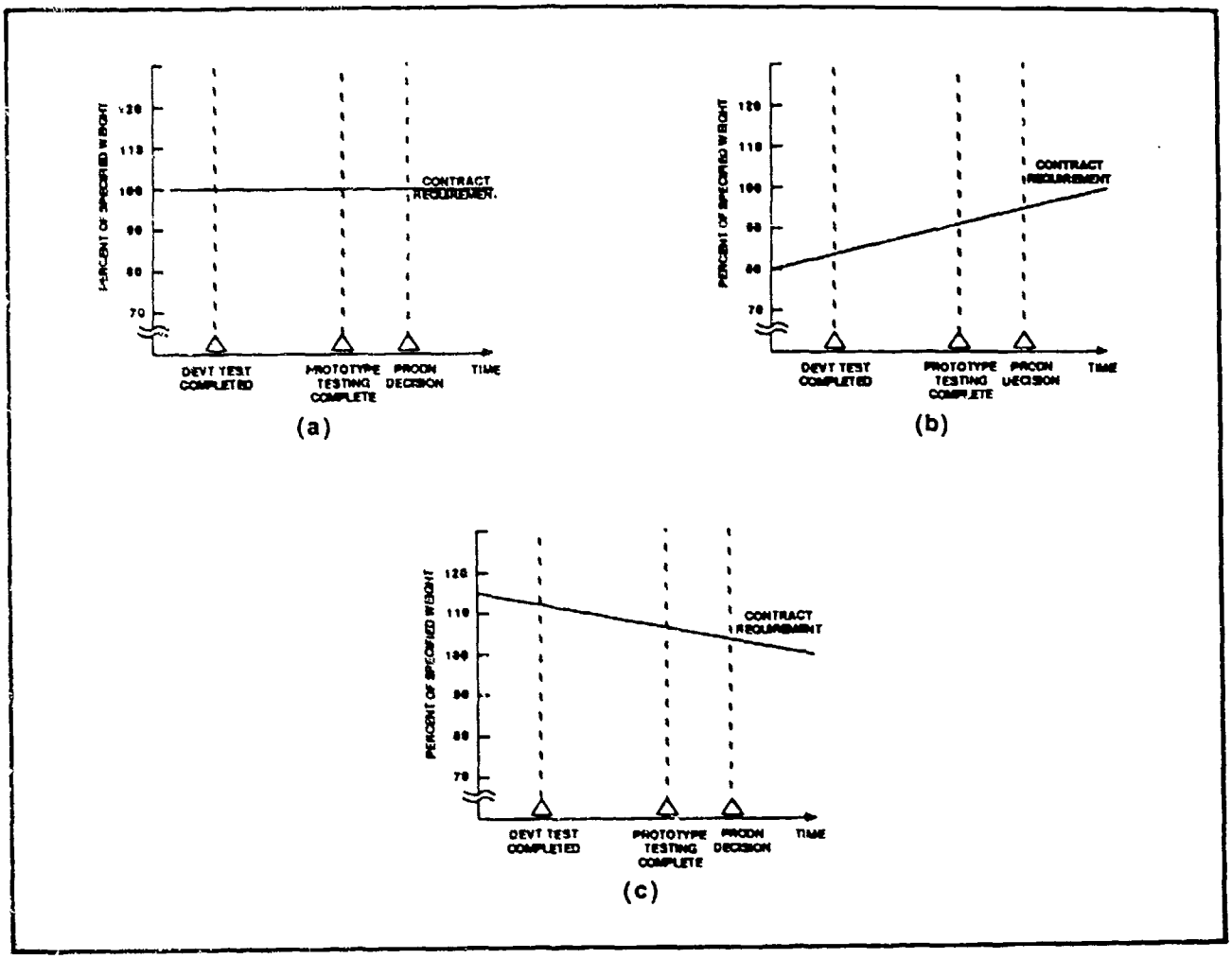
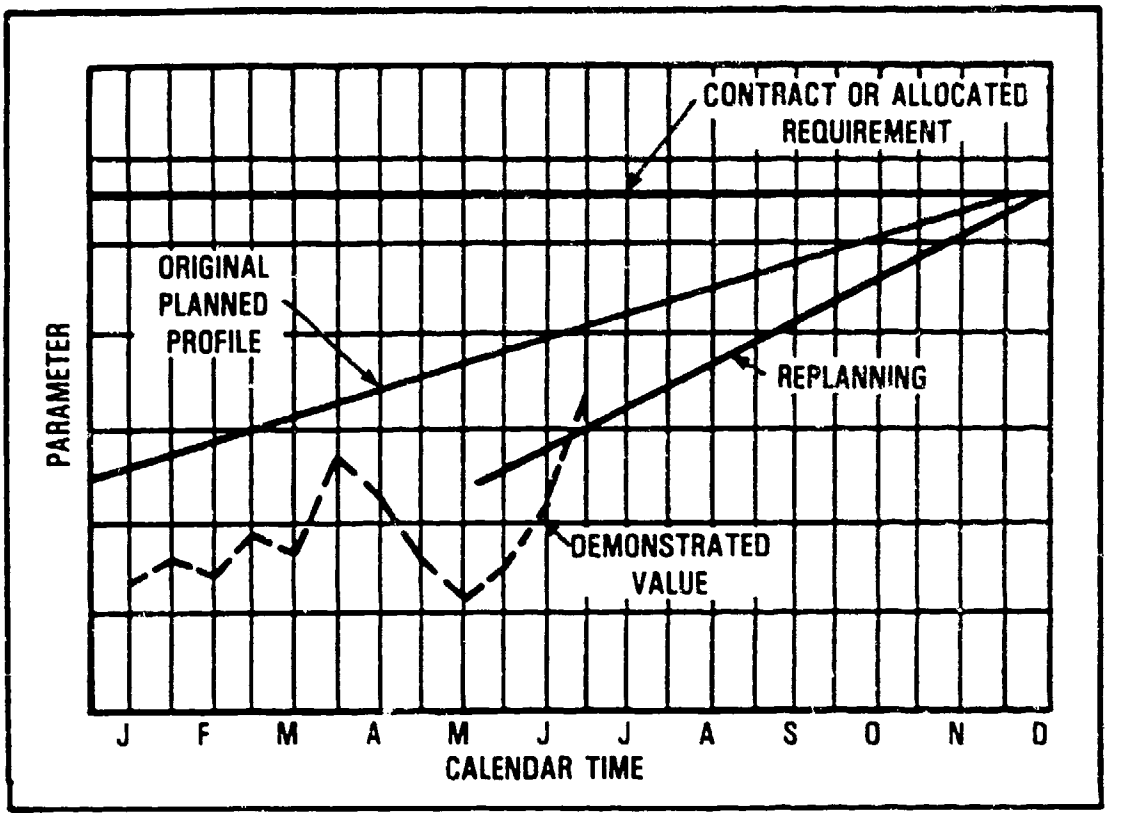


Figure 14-9
Pre-planning of TPM Profile

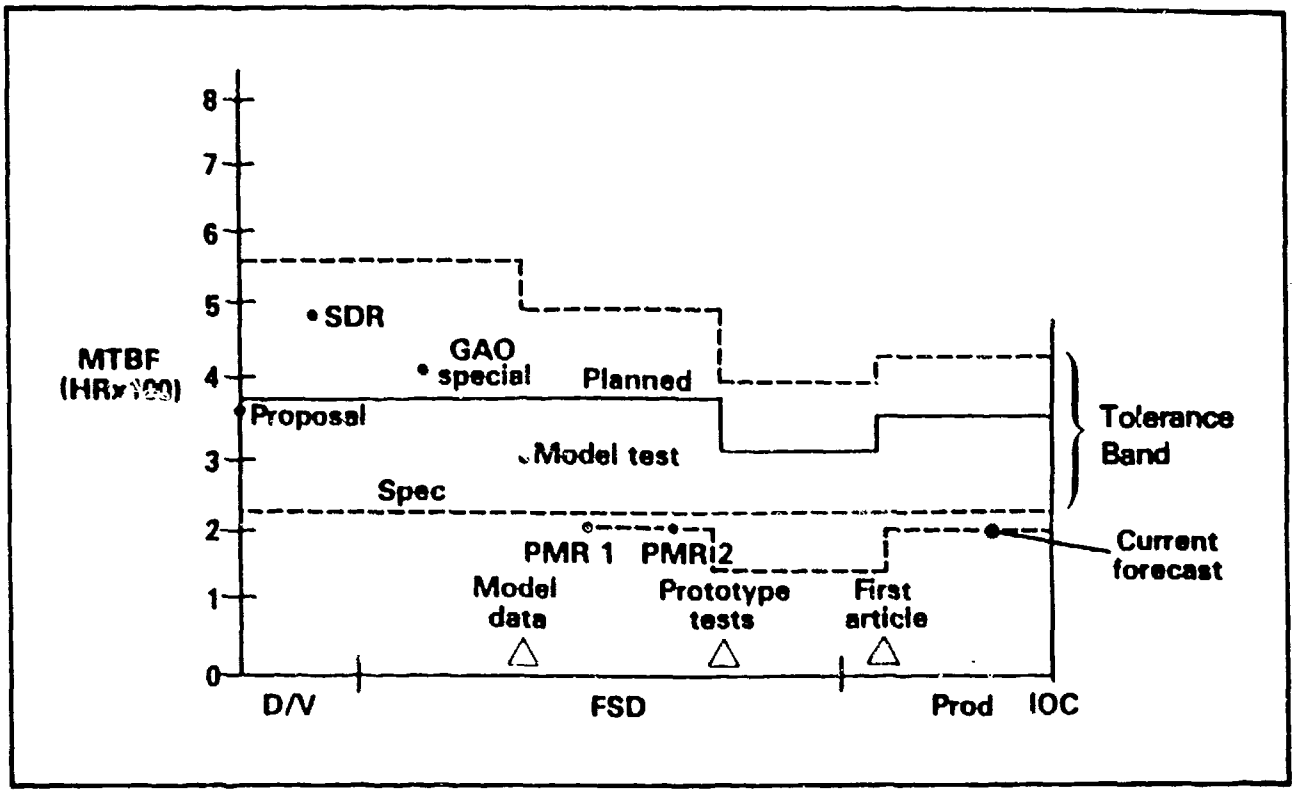


in process. Where trade studies indicate that cost or time to achieve a planned requirement is excessive, the requirement could be relaxed and new profiles established. This will usually involve adjustment of other parameters or parameter sets. Figure 14-9 illustrates the replanning of a profile based on demonstrated values.

The utility of all TPM assessment and forecasting methods is usually enhanced by establishing a tolerance band as part of the planning process for each profile. Figure 14-10 illustrates the tolerance band for a TPM parameter as it would be indicated on a TPM report. The boundaries of the tolerance band reflect the known limitations of the estimating method being used and past experience. They define the region within which it is reasonable to expect that the specification requirement will be achieved within cost and schedule constraints. Use of both upper and lower bounds on each parameter permits management by exception while providing notice of both underachievement and overachievement trends. Note that the example in Figure 14-10 shows a current forecast outside of the tolerance band.

Tolerance limits for performance profiles are normally established by the contractor during the D/V phase, with review and approval by the government program office. Since TPM is the Program Manager's early warning system, this review should include top-level management review of both the profiles and tolerance bands. An alarm

Figure 14-10
TPM Report Format



system is valuable only if activation levels are realistic. False alarm frequency will have a major long term impact on the confidence of contractor and government Program Managers in using this tool. Confident management by exception requires that tolerance band limits be reviewed at least yearly.

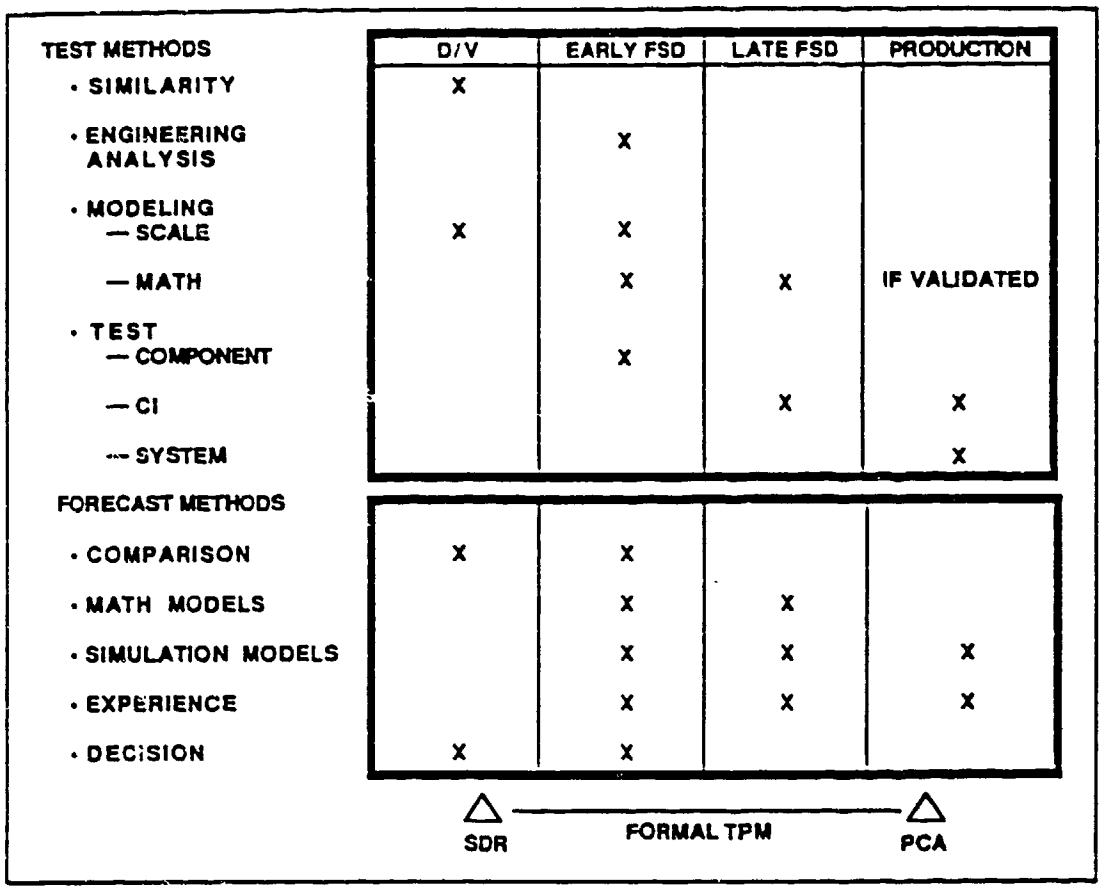
14.5 ASSESSMENT METHODS

There is a wide range of methods available for assessment of technical performance. During the D/V phase, analysis may be the only way of assessing what is probably largely a paper design. There is still a range of possibilities in terms of the method/ depth of analysis or degree of simulation.

Figure 14-11 illustrates typical methods used for both tracking and forecasting performance of selected parameters. The actual method(s) chosen for a particular program must be related to such factors as the type of TPM parameters selected, maturity of program, etc. Each method has associated costs, often requires development time, and in turn provides a specific level of confidence. The government and industry TPM managers must carefully trade off program needs for confidence in both tracking and forecasting with the related costs.

During system design and development, achievement to date is tracked at each assessment milestone, for each selected parameter, and at each specified level of the

Figure 14-11
TPM Methods



WBS. These point estimates, based on either analysis or testing, are then used to forecast the expected value that will be achieved at the end of the FSD phase, when the production decision is scheduled, or the initial operating capability (IOC), as the program office chooses.

If any demonstrated or forecast value falls outside the planned tolerance band, corrective action plans are prepared by the contractor and reviewed with the government program office. Each deviation is analyzed to determine cause and to assess the impact on higher level parameters, interface requirements, and system cost-effectiveness. Alternate recovery plans are developed showing fully explored cost, schedule, and technical performance implications. Where performance exceeds requirements, opportunities for reallocation of requirements and resources are assessed.

14.6 REPORT GENERATION

Parameter assessment for lower levels of the WBS can often be taken directly from test data or analysis that only involve one or two contract configuration items. System level parameters cannot be measured directly until very late in the acquisition cycle -- perhaps long after system responsibility has

shifted from the contractor to the government. For this reason, it is important that both contractor and government management conduct a thorough review of all simulation and summation models used to generate system level TPM reports during design development.

Through summary (system level) TPM reports, both the procuring agency and contractor management may quickly identify deviations from the planned parameter profile. The simplest example is the system weight parameter. Total weight is usually a summary level parameter, and a simple arithmetic summation of the actual weight of every part of the system must not exceed the total allowable weight for the system being developed. Each WBS product element would be allocated a specific or maximum weight. During design, development, and test phases, the weight of each WBS product element would be estimated, analyzed, measured, reported, and then accumulated through the simple summation model to arrive at a total system weight. Other parameters require much more complex summation models. Reliability and maintainability summation models require information on mean time between failure and mean time to repair of subsystems and components, typical mission profiles, intended mission mix, and maintenance manhours per operation hour.

To the degree the government PM has confidence in the choice of parameters, method of assessment, and fidelity of data, these reports will provide a valuable management tool for justifying or updating predictions of operational behavior, operational availability, and life cycle cost.

14.7 REPORT FREQUENCY AND TIMING

The effective tailoring of reporting requirements is one of the most difficult tasks facing the government PM and a major objective of the acquisition streamlining initiative outlined in Chapter 10 of this guide. Reporting requirements must be tailored considering such factors as:

a. Program technical risk

b. Program complexity

c. Program office size and organization

d. Amount of engineering development

e. Number of (competing) contractors

f. Size of program

g. Acquisition phase of contract

h. Contractors' track record.

One strategy that could be employed would be to specify a minimum level of formal reporting, but require that the contractor utilize the TPM system as a technical management tool and maintain records of internal actions.

Whenever an engineering specialty plan is changed, or deviation from planned technical performance values is reported, traceable records must be maintained. Likewise, the procuring agency usually reserves the right to require the contractor to discuss the records and TPM reports at any level of the WBS whether or not they are contract data requirements list (CDRL)

items. The capability to examine, on an exception basis, TPM data on low level WBS elements is crucial to the identification of effective corrective actions. The availability of this back-up information should also substantially reduce the frequency with which other than top summary level reports are required by the program office.

If possible, report delivery requirements should be correlated with the assessment points defined in the planning profiles. In the examples of Figure 14-8, each profile specified three assessment points: "completion of development testing," "completion of prototype testing," and "production decision." TPM assessment points are normally planned to coincide with the planned completion of significant design and testing tasks, program reviews, and decision milestones. These points are also prime candidates for contractually required report deliveries. Figure 14-12 shows a more realistic TPM report with reference to the related program events. Effective streamlining requires reporting schedules that are carefully matched to the expected level of design activity affecting each parameter. Reports may be prepared monthly or yearly, as appropriate. Management by exception plans may permit reporting of only those parameters outside established tolerance limits. On-line automated transmission of TPM data is now often feasible to reduce administrative costs.

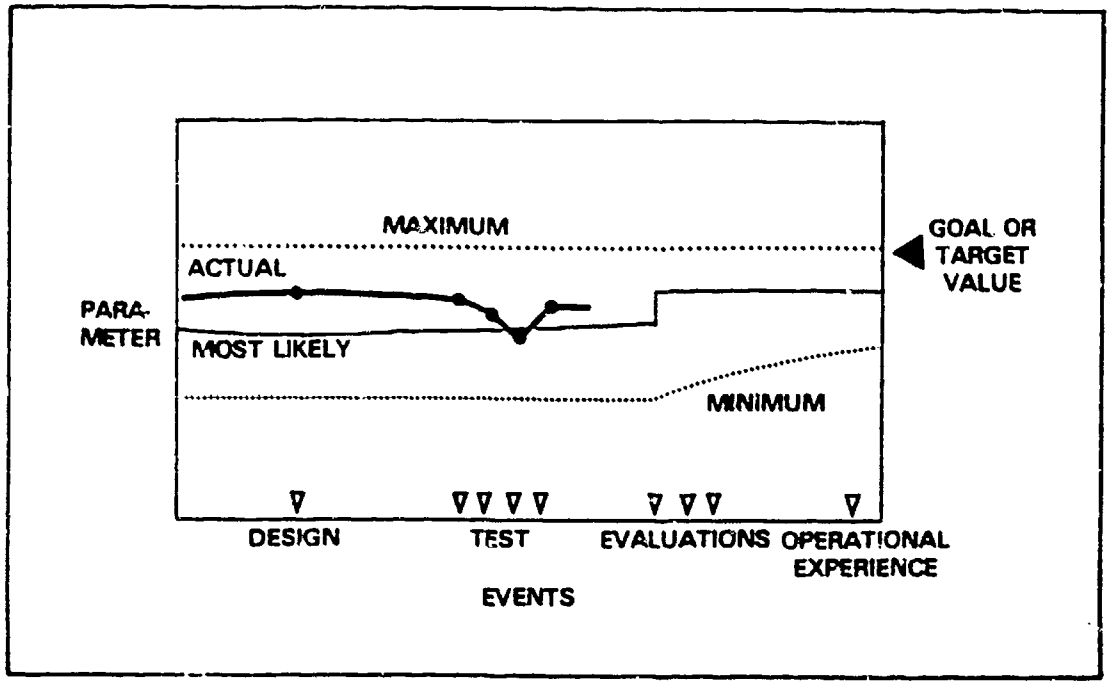
Typical candidates for TPM performance achievement and reporting milestones are:

a. Design reviews

b. Critical item analyses

c. Breadboard tests

Figure 14-12
Typical TPM Report



d. Hardware validations

e. Performance tests

f. Environmental tests

g. Qualification tests

h. Reliability tests

i. Computer software tests

j. Integrated logistic support testing and demonstration

k. Operational readiness testing.

14.8 TECHNICAL PROGRESS REVIEWS

Periodic reviews between the government and contractor(s) are conducted to determine whether the planned technical program should be altered as uncertainties are disclosed, eliminated, or reduced. These reviews, usually held quarterly, are a planned part of the systems engineering management effort, not a reaction to technical problems that suddenly appear. They are used to seek opportunities to reduce or redirect program effort to effect economies in budget and time, as well as to increase or redirect program effort to overcome weaknesses that may develop in the planned program. TPM assessment update events for the corresponding product elements of the WBS may be scheduled to coincide with configuration item design reviews, system level technical reviews, or quarterly technical program reviews. This fresh documentation then forms the basis for the review agenda and analysis.

14.9 RELATION OF TPM TO SYSTEMS ENGINEERING

TPM is an essential element in the systems engineering process. Demonstrated values that signal potential risks of meeting specification requirements and design to cost goals provide important feedback information to specialty areas such as reliability and maintainability. Since selected TPM parameters often overlap with principal trade study criteria, predicted technical variances might impact the choice and/or weighting of criteria. Technical performance assessment depends on the use of engineering analysis, test, and evaluation to make periodic assessments of the status of the technical program in achieving the performance parameters it has established for the product system. These technical assessments resulting from TPM, when correlated to cost and schedule reports, provide the complete status of the program. They serve to identify any engineering or other technical problems requiring management attention, and to forecast the impact on program cost, schedule, and ultimate performance of any out of tolerance conditions.

14.10 REPORT FORMAT

TPM reports delivered to the program office are actually a compilation of individual TPM parameter assessments and may be prepared according to data item description (DID) DI-S-3619 [2]. Each report contains a comparison of planned and actual values, a design and analysis status, a variance analysis, and supporting information.

The TPM report includes the

demonstrated value, planned value, and demonstrated variance for the design at the time of the TPM, plus the current estimate, the current specification requirement, and the predicted variance for the end product. Determination of the current estimate is based on the demonstrated value and changes to the parameter value that can be attained within the remaining schedule and cost baseline. The performance comparison can be in tabular or graphic form.

The TPM summary report might also include a status of the design configuration, discussion of design and engineering investigations (e.g., experiments and tests performed), analysis that supports the demonstrated value, and a discussion of technical effort supporting the predicted profile leading to the current estimate.

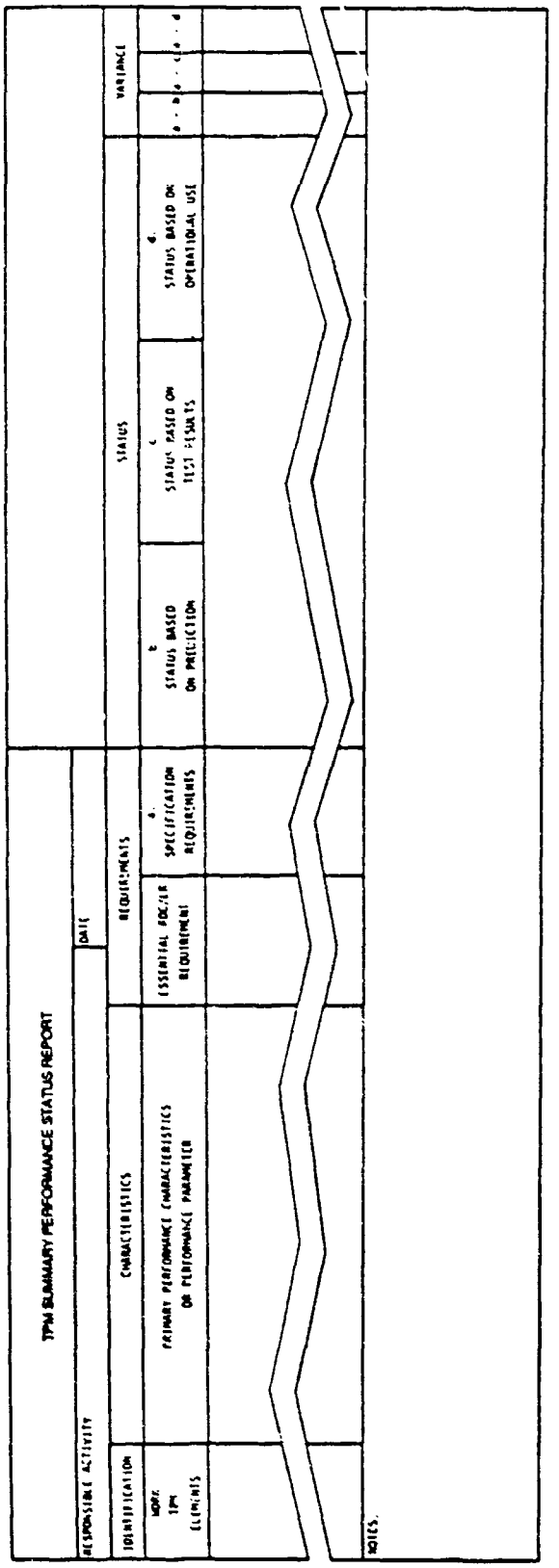
The precise reporting format must be tailored to program needs. The use of existing contractor report formats meeting the PM's needs is an economy encouraged by the acquisition streamlining initiative. Figure 14-13 illustrates one format for a TPM summary status report.

14.11 REFERENCES

1. MIL-STD-499A, "Engineering Management".

2. DI-S-3619, "Technical Performance Measurement Report".

Figure 14-13
TPM Summary Performance Status Report



CHAPTER 15

RISK ANALYSIS AND MANAGEMENT

15.1 INTRODUCTION

In the Department of Defense (DoD) context, risk can be defined as a potential occurrence that would be detrimental to plans or programs. Risk is measured as the combined effect of the likelihood of the occurrence and a measured or assessed consequence given that occurrence. The risk as perceived by the Program Manager (PM) will be different than that perceived by the Systems Engineer or the user. Risk is viewed from the perspective of the evaluator, hence, a risk evaluation must be conducted by someone with a broad perspective of the total program including business, technical and programmatic issues. Additionally, the impact of outside influences from both the government and industry require that multiple participants contribute to any successful evaluation.

Risk management is an organized means of identifying and measuring risk (risk assessment) and developing, selecting, and managing options (risk analysis) for resolving (risk handling) these risks. Several tools are available to assist the program office in understanding the danger signals that may indicate the program is off-track, determining the seriousness of the problem, and prioritizing corrective actions as necessary. With the addition of planning we call the process of planning, identifying, quantifying, and selecting methods to handle risk the management of risk. The general approach to risk management is presented here, while appropriate chapters incorporate specific recommendations for managing the risks associated with each systems engineering activity.

Risk management is not a separate program office activity assigned to a risk management branch, but rather is one aspect of a sound technical management program. Many of the systems engineering management techniques outlined in this guide (e.g., technical performance measurement (TPM), life cycle costing, configuration management (CM), template, trade-off analysis) are also risk management tools or techniques used for risk assessment and risk handling methods.

15.2 APPROACH

It is important that a risk management strategy be established early in a program and that risk be continually addressed throughout the system life cycle. Risk management includes several related actions: 1) risk planning, 2) risk assessment, 3) risk analysis, and 4) risk handling.

15.2.1 Risk Planning

Risk planning is the process to force organized purposeful thought to the subject of eliminating, minimizing, or containing the effects of undesirable occurrences. The individual assigned this task should instill a

sense of ownership with the functional managers so as to cause their continual examination of alternative solutions (handling) to the risk areas (problems). As with any process there are two basic elements: planning and execution, which include monitoring and control techniques.

15.2.2 Risk Assessment

Risk assessment is the process of examining a situation and identifying the areas of potential risk. The first step in risk management is to identify and assess all potential risk areas. This may include a survey of the program, customer, and users for concerns and problems. The thoroughness with which this identification is accomplished will determine the effectiveness of risk management.

Some degree of risk always exists in program, technical, test, logistics, production, and engineering areas. Program risks include funding, schedule, contract relationships, and political risks. Technical risks may involve the risk of meeting a performance requirement such as reliability, probability of first weapon hit, maneuverability or survivability, but may also involve risks in the feasibility of a design concept or the risks associated with using state-of-the-art equipment or software. Production risk includes concerns over quality, rework, producibility, packaging, manufacturing, lead times, and material availability. Engineering risks associated with user suitability include reliability, maintainability, operability, and trainability concerns. The understanding of risks in these and other areas evolves over time. Consequently, the risk assessment must continue through all program phases.

The methods for identifying risk are numerous. Any source of information that allows recognition of a potential problem can be used for risk identification. These include:

a. Systems engineering documentation

b. Life cycle cost analysis

c. Schedule analysis

d. Baseline cost estimates

e. Requirements documents

f. Lessons-learned files

g. Trade studies/analyses

h. Technical performance measurement (TPM) planning/ analysis

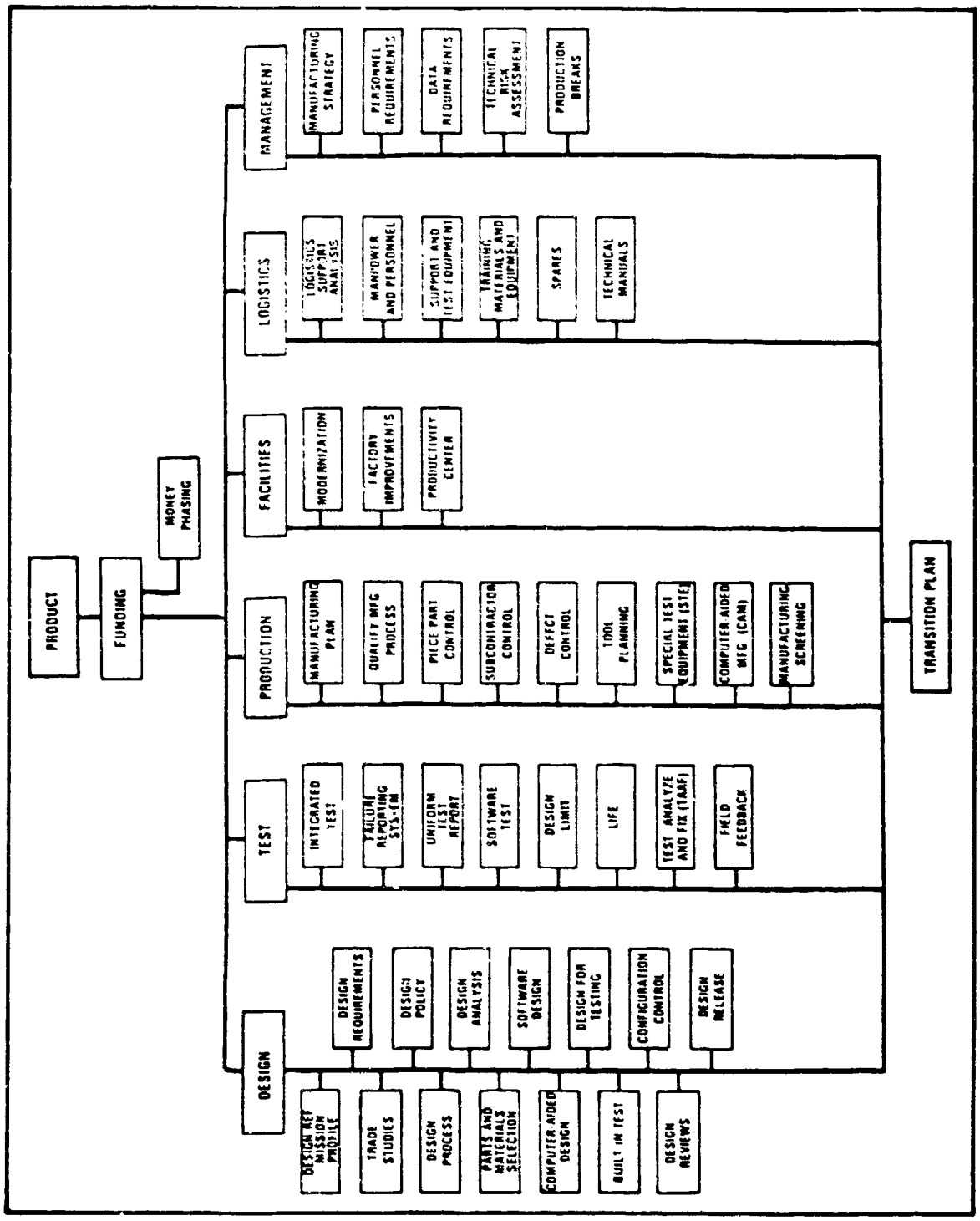
i. Cost Models

j. Scheduling Models

k. Work Breakdown Structures (WBS)

DoD 4245.7-M [1] provides a structure, which is becoming a standard within DoD, for identifying technical risk areas in the transition from development to production. The structure is geared towards development programs but, with modifications, could be used for any acquisition program. The structure, shown in Figure 15-1, identifies a template for each major program technical

Figure 15-1
DoD 4245.7-M Risk Management Templates



management and systems engineering activity.

Each template identifies potential areas of risk. Overlaying each template on a program allows identification of mismatched areas, which are then identified as "at risk." Having used all applicable templates, the Program Manager will have created a "watch list" of production transition risk areas and can prioritize control actions -- many of which will be the responsibility of systems engineering. DoD 4245.7-M [1] describes technical methods for reducing the risk in each identified area (see Figure 15-2).

High risk areas may reflect missing capabilities in the PM's organization or in supporting organizations. They may also reflect technical difficulties in the design or development process. In either case, "management" of risk involves using program management assets to reduce the identified risks.

One approach for identifying technical risk areas at the system level is to use the guidance provided in Reference [2]. This document outlines a rigorous process for identifying specific technical risks at the functional level and translating this detailed information through several steps into a program summary-level risk assessment, as shown in Figure 15-3. In this way, risks are identified at management levels appropriate to monitoring or correcting the situation.

Risk monitoring and reporting structures usually identify five major risk categories: design (performance), test, production, cost, and management. These categories should be examined at the program, subsystem, and functional levels. Starting from the bottom, data are developed for these five engineering indicators in order to rate them according to "high," "medium," or "low" risk categories at the subsystem level. Results of these assessments should be summarized for each

Figure 15-2
Sample Risk Management Template (DoD 4275.7-M)

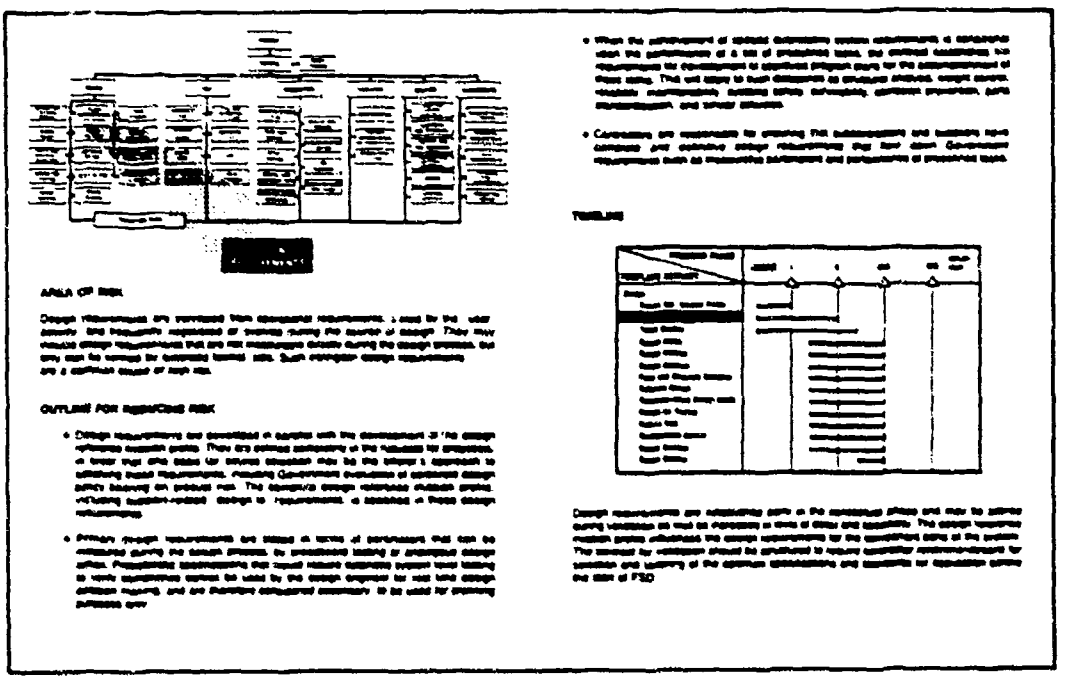
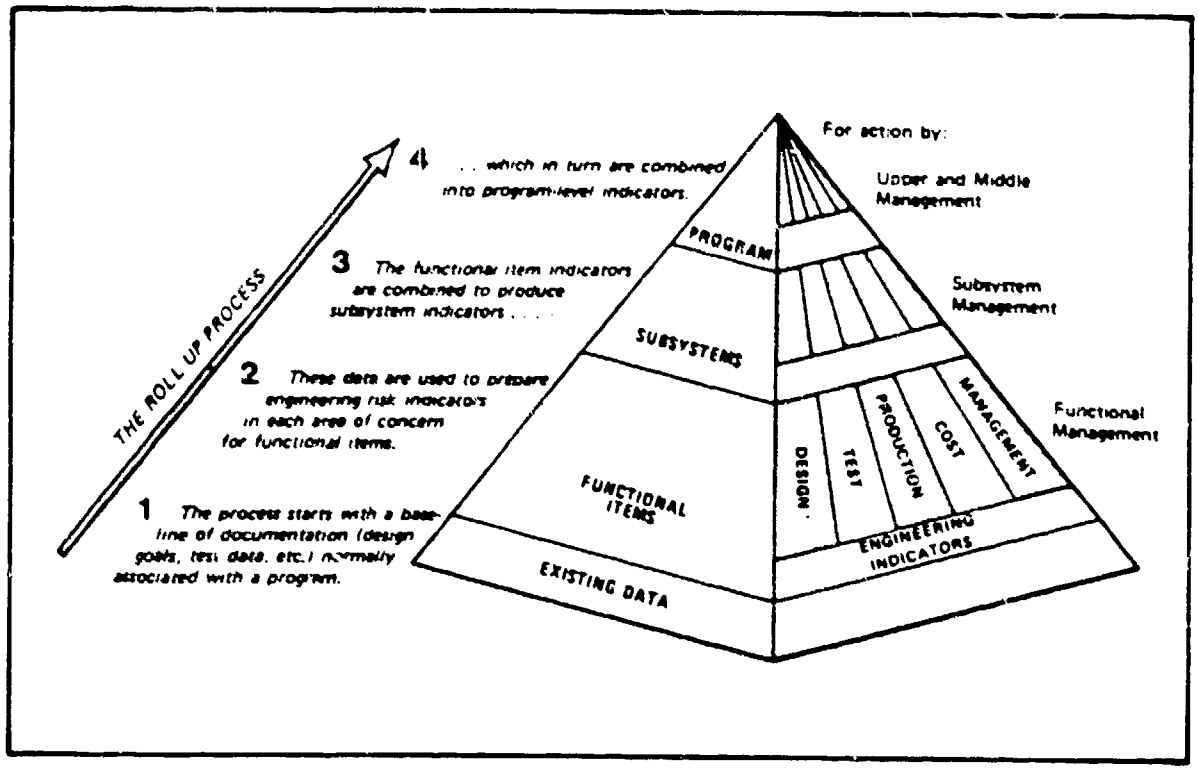


Figure 15-3
Technical Risk Identification at Appropriate Management Levels

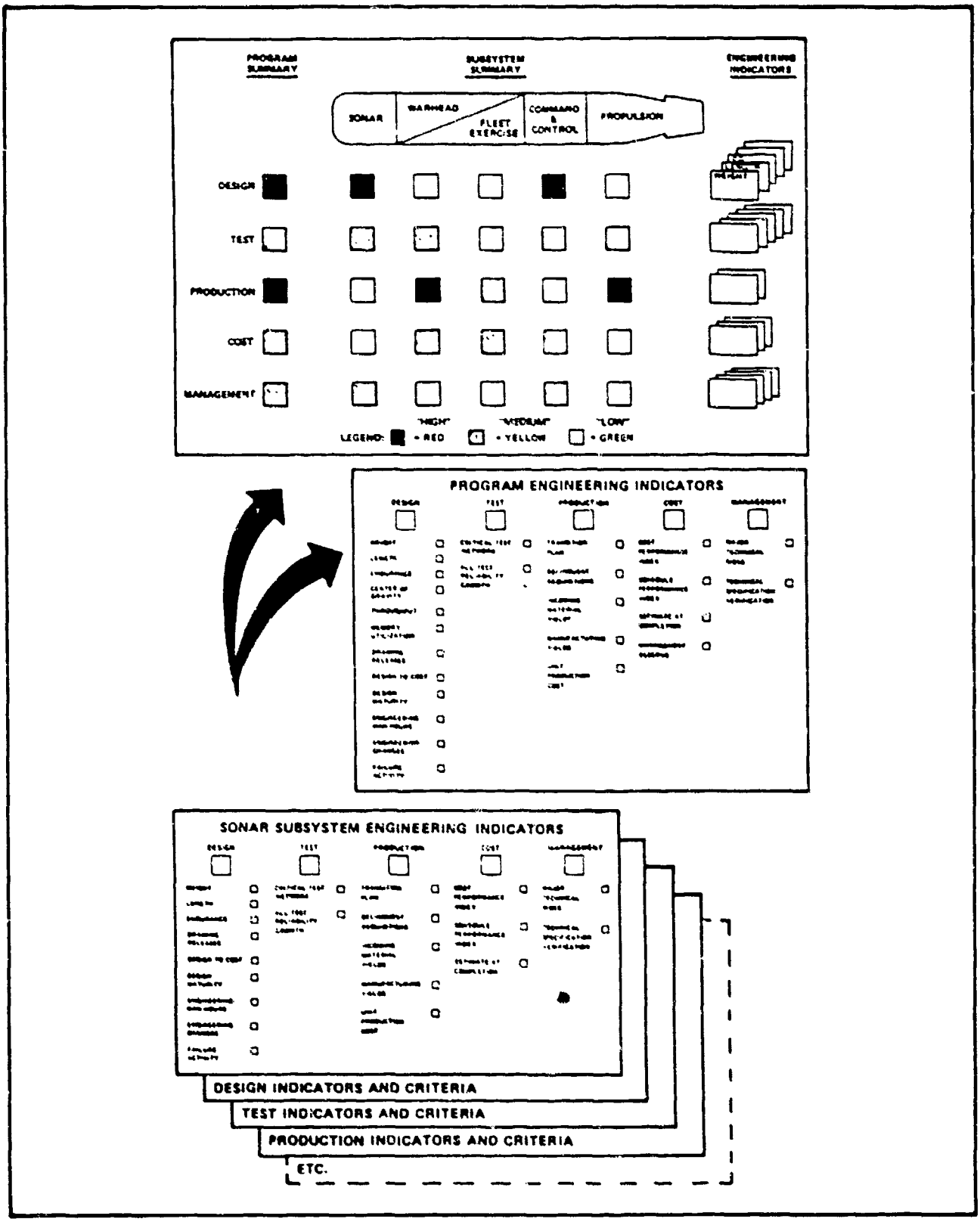


subsystem to provide a system overview, as illustrated in Figure 15-4 for a torpedo development program, using template risk reduction methods. (Red-yellow-green notation indicates high-medium-low risks respectively).

A risk viewed as easily manageable by some managers may be considered hard to manage by less experienced or less knowledgeable managers. Consequently, the terms "high," "medium," or "low" risk are relative terms. Some managers may be risk averse and choose to avoid recognized risk at all reasonable cost. Other managers may be risk seekers and actually prefer to take an approach with more risk. The terms "high," "medium," and "low" risk may change with the turnover of managers and their superiors as much as with the program events.

Another approach is to use the work breakdown structure (WBS) as the framework for risk analysis (refer to Chapter 9 of this guide). To use this approach, each element at level 3 of the WBS is further broken down to the fourth or fifth level and is subjected to a quantitative risk analysis procedure. Items at system, segment or group, or subsystem levels, as well as management items, are assessed using attributes such as maturity and complexity of hardware and software items or the dependency of the item on existing systems, facilities, or contractors to evaluate their risk levels. Risk may be identified at the summary level of the WBS by the absence of system components, such as training devices.

Figure 15-4
Variation of Risk Identification Products
With Management Level



Lower levels of the WBS are typically used for allocation of risk control responsibilities.

More recently, PMs have recognized that it is the systems engineer and his design methodology that decides what technology will be selected, tolerances assigned, material finishes required, production processes called out, and tests required during the production process. Each of these examples can be recognized as effecting the quality and thus the cost of the item in production. It has been recognized that the quality desired in production must be addressed during the design phase by having the production engineers work with the design engineers to ensure the production process is developed concurrently with the actual design of the weapon system. The organization that does not have production engineers working to concurrently address the production process with the design will most likely face the following risks: lower quality and higher rework, a much higher first unit cost, a failure to reduce cost while the transition problems are being resolved, and then a recognition of cost opportunity lost (by trying to work a production process that was identified by design but is found to be less than optimal for the design trying to be produced).

In house design reviews are an excellent means for identifying the risks being taken through the various technical approaches on a program. Additionally, when industry presents their design reviews to the government program team, MIL-STD-1521B [3] requires that the elements of technical risk in a program be included in each of the program reviews. This is further discussed in Chapter 12 of this guide. Risk areas and levels should be identified during trade-off analysis and included if appropriate in the review agenda. Risk-handling options should be addressed at about the WBS level 3, during the program review. The discussing of system and program risk in program reviews is an essential element of the technical management process.

The value in each of these approaches to risk identification lies in the methodical nature of the approach, which forces disciplined, consistent treatment of risk. However, using any method in a "cookbook" manner may cause unique risk aspects of the program to be overlooked. Before acting on the outcome of any assessment, the Program Manager must review the strengths and weaknesses of the approach and insure that other factors that may introduce technical, schedule, cost, and program risk have not been overlooked as a result of the method used.

15.2.3 Risk Analysis

Risk analysis requires conducting an analysis of the program, as well as any environmental changes, to determine the probability of events and the consequences associated with the potential actions that could affect the program. Many tools exist to aid in the analysis, such as schedule network models and life cycle cost models. The purpose of risk analysis is to discover the cause, effects, and magnitude of the risk perceived, and to develop and examine alternative options.

Describing and quantifying a specific risk and the magnitude of that risk usually requires some modeling. Typical tools for

use in risk analysis are:

a. Schedule Network Model - Venture Evaluation Review Technique (VERT), or Program Evaluation Review Technique (PERT) (see References [4] and [5]) with dependent activities networked for analysis of the impact to any activity.

b. Life Cycle Cost (LCC) Model - tailored for the phase of development and type of system (LCC models are discussed in Chapter 17 of this guide).

c. Quick Reaction Rate/ Quantity Cost Impact Model - such as Defense Production Engineer Support Office model.

The first two models are used to examine schedule and program cost risk as various options for procurement strategy, logistics maintenance levels, and contractor support are considered. The quick reaction model is used when program funds are challenged, an action that happens frequently during the budget cycle. These challenges are most prevalent just prior to production and can severely affect the program's executability. The quick reaction model also permits examination of probable cost impacts for determining required budget allocation in program planning of various options, such as use of contractor maintenance, or joint software support facilities.

Network models identify the key interactions of the major activities throughout a program or a phase of the program. Most modern-day networks permit the probability of each activity to be varied so that the sensitivity of key parameters upon models of total cost or schedule can be examined. This information is used in determining resource allocation priorities.

For every area of risk, there is a method of analysis to determine the logical relationships of cause and effect. Some of the most frequent causes of program impact are production rate and quantity change, inadequate planning for production, and a failure to adequately prepare for the system support requirements. Test and evaluation is usually considered a risk reduction measure in that T&E identifies items, subsystems or systems that have identifiable shortfalls relative to the requirement.

A product of risk analysis is a "***watch list***". This is the identification of consequences that are likely to occur and the indicators of the start of the problem. An example of this is the cost risk of production due to an immature technical data package. When production starts before the technical data package has been adequately engineered for producibility, the first unit cost is higher than planned with a "***steeper than planned***" learning curve. This is the result of excessive producibility changes needed to achieve the planned production cost. Therefore, when the first article cost is estimated during production, it is time to reassess the technical data package for need to put more than planned emphasis on producibility engineering efforts. A typical watch list is structured to show the trigger event or item (for example, long lead items delayed), the related area of impact (production schedule) and later, as they are developed, the risk handling actions taken to avoid/ minimize the potential for or impact from that event (such as ensuring early identification of long lead items or placing contractor emphasis on

early delivery).

The watch list is periodically reevaluated and items are added, modified, or deleted as appropriate. Should the trigger events on the watch list occur during a program, there would be immediate cause for impact assessments to be updated and risk handling methods to be selected.

15.2.4 Risk Handling

Risk handling includes techniques and methods developed to reduce or control the risk. There is no risk management if there are no provisions for handling the identified and quantified risk.

The techniques for reducing or controlling risk fall into the following categories: 1) avoidance, 2) prevention (control), 3) assumption (retention), 4) transfer, and 5) knowledge and research.

To avoid risk is to avoid the potential failure consequence and/or its probability. In program management, risk avoidance may be reflected in the system concept selection and contractor source selection. Not every risk can be wholly avoided. An action that avoids one risk may simply transfer that risk to another area. The process of source selection allows the PM to identify the shortcomings of competitive sources so as to avoid sources having unacceptable risk.

Risk control is the process of continually sensing the condition of a program and developing options and fall back positions to permit alternative lower risk solutions. Technical performance measurement (TPM) and cost/schedule control system criteria (C/SCSC) are the best-known sensors. The process of developing alternative sources for production, parallel development for a critical research and design component, or getting priority for critical materials are all examples of risk control options. The requirements (in time and money) for development of these options determine the required sensitivity of the monitoring tools selected by the program office. A TPM or cost performance measurement (CPM) report giving 90 days notice of an impending failure is not helpful if the products of parallel development will take six months.

Risk assumption is an acknowledgement of the existence of the risk but a decision to accept the consequences if failure occurs. Most acquisition programs and all development programs must assume some risks. Most acquisition programs and all development programs must assume some risks. Identification, analysis, and selection of handling techniques allow the PM to assume the ***"right"*** risks, such as those with either low probability, low consequences or both. Those that are too hazardous to assume may be, at least partially, transferred to the contractor at appropriate premium cost.

Options for risk transfer from the government PM to the contractor include product performance incentives, warranties, cost incentives, and fixed price contracts. These are agreements with the contractor that the consequent "costs" of failure will be assumed by the contractor at an agreed upon price which may be in terms of profit dollars, product performance modifications,

or schedule changes.

Knowledge and research as a method for risk handling is a continuing process that enables the participants to perform risk reductions through both probability and consequence modification such as:

a. Early initiation of development activities

b. Implementation of extensive testing

c. Development of simulations to predict performance.

Risk managers draw on methods, techniques, and tools available in decision analysis disciplines to determine the preferred course of action. Various decision analysis tools, such as trade-off analyses (see Chapter 8 of this guide), are described elsewhere in this guide. In addition, the principles of utility analysis and decision making under uncertainty (see Reference [4]) provide useful tools in many applications. One special risk abatement tool developed by the Army is Total Risk Assessing Cost Estimates (TRACE). The principle of TRACE is to consider the cost of risk for a command (including all its ongoing programs) and to pool resources against the total assessed risk for apportionment according to needs over time. Since TRACE funds are usually a calculation based on probability and consequences of known or perceived problems, they do not provide for the risks identified as "unknown-unknowns" such as a labor strike at a production facility, fires, acts of god or other non perceived problems. Since the funds set aside would always be only a sub-set of the total unknowns (e.g., both the known-unknowns such as inflation variance, schedule variance, or performance shortfalls, and unknown-unknowns) they would never cover all risks. This would require that the funds set aside for TRACE were indeed "risk" funds and not management reserve or funds for highly probable unknowns.

15.3 AVOIDING COMMON TRAPS

Identified risks must be managed so as to mitigate, to the extent assets allow, their potential to adversely affect the program. All levels of management must be sensitive to hidden ***"traps"*** that may induce a false sense of security. If properly interpreted, these signals really indicate a developing problem in a known area of risk. NAVSO P 6071 [6] offers guidelines to the PM in implementing DoD 4245.7-M [1] at the working level. The document follows the same template structure as DoD 4245.7-M [1]. Each trap is accompanied by several "warning signs" that show an approaching problem and the likely "consequence" of failing to treat the problem at its inception. The document also suggests "escapes," or ways to avoid these common traps, and notes attendant "benefits" from exercising positive control over that technical risk area. An example is shown in Figure 15-5.

The ability to turn traps into advantages suggests that much of the technical risk in a program can be actively mitigated, not merely watched and resolved after a problem occurs. In some instances it may pay to watch and wait. If the probability that a certain problem will arise is low or if the cost exceeds the benefits of "fixing" the problem before it happens, a do-nothing alternative may be advisable. Effective risk

Figure 15-5
Sample Risk Reduction Approach ("Best Practices")

management makes selection of the do-nothing alternative a conscious decision rather than an oversight and should trigger an appropriate addition to the watch list and perhaps to formal TPM reporting requirements.

"Best Practices" acknowledges that all of the traps have not been identified for each template. The traps are intended to be suggestive, and other potential problems should be examined as they arise. It is also important to recognize that the sources and types of risk evolve over time. Particularly during the transition from development to production, the nature of potential problems shifts. Risks may take a long time to mature into problems, so attention may be properly focused in advance of the current acquisition phase.

15.4 RISK MONITORING

Risk items are monitored continually by systems engineers and risk reduction actions are recommended. Inherent in the monitoring of technical performance design risk is evaluation of predicted performance against specified requirements. Appropriate performance parameters for risk monitoring are established at the top level, together with their contributors (or allocations) at lower levels. Properly managed systems engineering ensures that the risks associated with each design decision are identified and treated in risk assessment updates: how to recognize the risk if the potential problem should occur (e.g., higher failures when stress is over 60 foot-pounds) and what actions should be taken if the problem is due to the potential risk area (e.g., use substitute component X27-46). In addition, for the total system concept, the relationship between the systems engineer and the project control chief should be indicated, showing the contribution of each to the selections made in the decision process.

The risk item performance parameter is monitored as part of TPM, and action is taken dependent on its effect on system level performance. Costs and schedules are monitored by reports generated to satisfy C/SCSC (refer to MIL-STD-881A [7]).

15.5 DOCUMENTATION

Program risk documentation requirements imposed on contractors vary and are highly dependent upon the nature of the program contract type and the program phase. The following contractor documentation may be required:

a. Risk Management Program Plan

b. Risk Sensitivity Analysis

c. Risk Handling Plans

d. Risk Reduction Reports.

15.5.1 Risk Management Program Plan

A Risk Management Program Plan may be initiated by each contractor in the Concept Exploration/ Definition (C/E) phase and updated at each phase of the development cycle to reflect a degree of detail and approach consistent with phase objectives. The program office should consider the contractor's approach to risk management in its evaluation of contractor

proposals.

A government-approved Risk Management Program Plan may be required of the prime contractor before the System Design Review (SDR). If no risk management plan is required, the industry prepared Systems Engineering Management Plan (SEMP) should describe the risk analysis approach being used for the program.

The Risk Management Program Plan would describe programmatic aspects of risk planning, risk identification, risk assessment, risk reduction, and risk management functions to be performed by the contractor. The risk management plan should relate the contractor's approach for handling risk to the options (e.g., avoidance, prevention, transfer) discussed in Section 15.2.3. A suggested outline for the plan is given in Figure 15-6.

The plan should be tailored to reflect program concerns. It should describe a risk reduction program with minimum cost and schedule impact, using a minimum number of personnel. It should describe a simple but complete method of surveying individual potential risks and identifying the degree or level of risk at each system level. The plan should also describe how an iterative risk assessment process is applied at all WBS or Contract Work Breakdown Structure (CWBS) levels for each previously identified risk as the design progresses.

The plan should describe the role of risk assessment in design reviews, technical performance monitoring, and the change control processes. It should describe the available methods of risk reduction, monitoring, and management for each defined and assessed level of risk.

The plan should provide the means for ensuring that risk assessment of associate contractors and subcontractors is consistent and compatible with the prime contractor's methods.

The Risk Management Program Plan should require that a separate Risk Handling Plan be prepared for each high risk item, identifying the timing for its development and assigning originator and review responsibility. The plan should also require that Risk Reduction Reports be prepared for each item classified as medium or high risk. It should describe the role of the plan in the program, how it is to be implemented, its frequency, its relationship to systems engineering, and how the risk program is to be managed. The approved data item description for contractor-generated Risk Management Plans is UDI-A-23862 [8].

15.5.2 Risk Sensitivity Analysis

The Risk Sensitivity Analysis presents the program's sensitivity to risk in terms of schedule and cost. It examines the impact of each risk element down to level 3 of the WBS on the overall program cost and schedule. The analysis relates directly to the Risk Management Program Plan and first summarizes the potential cost and schedule if no risk reduction actions are taken. This summary is followed by a detailed examination of each WBS area to determine item should be prepared by the contractor in accordance with the SEMP and submitted to the government for review and approval

Figure 15-6
Sample Risk Management Program Plan Outline

I. Introduction

1. Overview
2. Applicable Documents/Definitions
3. Management Organization/Responsibilities
4. Scheduled Milestones/Reviews

II. Identification and Assessment

5. Survey and Identification
6. Risk Assessment Models
7. Flow/Level Assessment/Treatment
8. System Hierarchy and Risk Tree

III. Analysis and Reduction

9. Reduction Methods
10. Analysis Methods
11. Risk Abatement Plan
12. Prototyping/Simulations/Tests

IV. Appendices

A. Survey Form
B. Report Format and Content
C. Assessment Tables/Graphs
D. Plan Format and Content

prior to implementation. These plans could be developed at the end of each phase for implementation in the next phase or upon identification of a high risk item by the contractor. Progress to plan should be reviewed at program technical reviews. Suggested plan contents include:

a. Statement and assessment of risk/problem

b. Consequences of failure

c. Alternatives considered with risk and cost of each

d. Recommended risk reduction/abatement method

e. Implementation impact statement (cost/ schedule/ technical)

f. Responsible organization and personnel

g. Implementation start date and key milestone schedule

h. Criteria for closure of this risk activity

i. Decision points

j. Recommended back-up developments and tests including cost.

Risk Handling Plans should be limited to the highest risk items if possible, as they are manpower and/or cost intensive. They

should also be tailored to fit the program and to satisfy government requirements.

15.5.4 Risk Reduction Report

Contractors should submit a Risk Reduction Report to the government for each medium or high risk item (not less than one report for each level 3 WBS element). The report should be updated periodically, as specified by the government, to describe the status of risk reduction programs being implemented. The updates should be expected to coincide with technical reviews, and to proceed government in-house reviews such as those scheduled with higher headquarters.

15.6 REFERENCES

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10. DoDI 5000.2, "Major System Acquisition Procedures".

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CHAPTER 16

MODIFICATION MANAGEMENT

16.1 INTRODUCTION

Department of Defense (DoD) weapon systems undergo modifications throughout their life cycles. For example, 1) a typical tactical aircraft goes through four to five major modifications after deployment, 2) the M-60 tank has undergone 35 changes since initial production, and 3) the UH-1 helicopter has undergone 45 changes. What this means is that 1) a substantial proportion of the DoD budget is used to ***modify existing systems vice developing new systems***, and 2) the management of these modifications or changes to existing systems becomes more critical and requires special emphasis on integration, implementation, and baseline control. Modifications are used to correct system deficiencies to provide increased performance, counter new threats, lower life cycle costs, extend the system's useful life, or remove obsolete capabilities.

Planning for future modifications starts in development. Design decisions made in development will affect the flexibility of the system to incorporate changes throughout its life cycle. Once the system is produced, the decisions are costly to reverse. Especially during the transition from development to production, ease of future modification must be considered in conjunction with performance, cost, and manufacturing and producibility considerations. For example, it may be easier or less expensive initially to weld a seam (the welded seam may reduce weight, thereby enhancing performance); whereas, if modification considerations were evaluated, a bolted seam might be more cost effective over the system's life cycle, or might simplify a future upgrade by allowing a modification to be accomplished in the field.

Modifications sometimes occur after production has started but, due to the length of the Production phase, it may be possible to incorporate the modification into some of the items during their assembly/ fabrication instead of waiting until after they have been "produced." Incorporating changes into produced items is complex since the produced items may be deployed in many locations with multiple agencies responsible for their operation, support, maintenance, and repair. Managing this aspect of modifications tests the best management talents and requires considerable effort to realize successfully.

During production, successful modification programs are dependent on a highly disciplined configuration management (CM) system. This is especially true when large numbers of items are built over prolonged periods and are widely deployed (e.g., the M-60 tank or the F-4 aircraft). The ability to make even minor corrections at remote facilities is often limited. The use of a CM system is therefore mandatory throughout the life of the system. Adequate communication channels are essential for

transferring modification data from the organization installing the modification to the CM center, so that up-to-date configuration status accounting records can be maintained.

There is a clear distinction between post-production modifications and engineering change proposals (ECPs). When systems receive changes during production, only those systems that have been fielded can be modified through the product improvement program. For example, Army systems may not receive product improvements until they are type classified standard and accepted into the inventory. Those systems still in production must be modified by ECPs using production funds or have modification kits installed after they have been delivered to the user. Research, Development, Test and Evaluation (RDT&E) funds are used to develop modifications that increase the operational envelope of a system; Operation and Support (O&S) funds are applied to modification kits. When system improvements are very large, such as the CH-47D upgrade, they are budgeted and funded as if they were new development efforts. Currently, the cost of post-development software improvements are paid for with O&S and RDT&E funds.

If a modification must be incorporated into a number of different systems (e.g., installation of the cruise missile on ships, aircraft, and missile carriers), this multiplies the complexity of the modification. Tailored installation instructions and kit interface components are required for each application. Communications with agencies and users and modification management problems also increase dramatically.

16.2 APPROACH

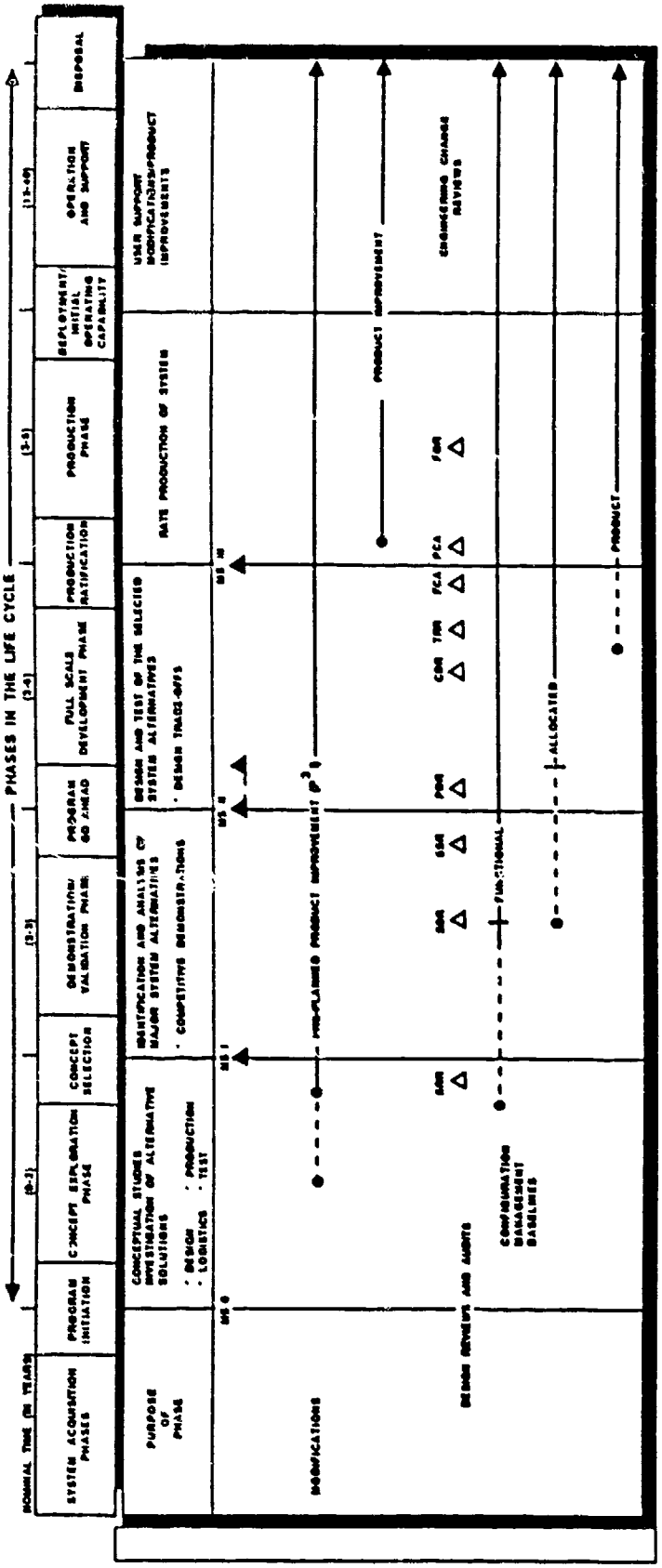
Modification to an existing hardware or a software configuration item (CI) is a change to its form, fit, or function that revises its physical or functional characteristics. The general phasing of modifications in the acquisition process is shown in Figure 16-1.

Modifications are classified in many ways. No matter how each Service component may classify modifications, there are two major categories modifications fall into: 1) product improvements and 2) preplanned product improvements.

Product Improvement (PI) - PIs are applied to already fielded systems. PIs are undertaken in response to con- gressional mandates, cost reduction efforts, reliability/ maintainability/ availability improvements, rationalization, standardization, interoperability considerations, or safety factors. CIs are also undertaken to improve operational capabilities. In addition, PIs may be used to correct system problems discovered after fielding, although less than 10 percent of PIs are needed for this purpose.

Pre-Planned Product Improvement (P^3I) - Recent initiatives to improve the DoD acquisition process have included P^3I. This is an attempt to field low cost, low risk systems with preplanned design modifications keyed to foreseeable technological breakthroughs and expected changes in user needs. P^3I is a systematic and orderly acquisition strategy to facilitate evolutionary, cost effective upgrading (growth) of a system's capabilities throughout the life cycle.

Figure 16-1
Time Phasing of Product Improvement Modifications



The commercial aircraft industry uses this concept when planning families of aircraft from the same baseline design. Further detail on P^3I is given in Section 16.4.

16.3 IMPLEMENTATION

The DoDD 5000.1 [1] acquisition cycle can be thought of as composed of the following five steps for modification programs: 1) need, 2) design, 3) test, 4) manufacture, and 5) operate and support. The need and test steps are like those for other programs and require no additional explanation here.

During the design step, the modification and associated modification kit are designed. The modification kit is the collection of hardware, software, data, and instructions that incorporates the modification into the existing system. The modification should be designed so that it can be incorporated in a produced item without degrading its performance, if possible. Integrated logistic support (ILS) planning for the modified system must be done during development.

The manufacture step involves manufacturing and assembling the modification kit. The kit includes not only the hardware and software, but also the data required to install the modification and to operate and support the modified system. The kit may also contain unique tools, spares, and other items necessary to incorporate and support the change. Kit production and delivery schedules must be fully coordinated with the installation schedule.

Implementation of the installation schedule becomes more complex as the number of systems that will receive the modification increases and as the number of modifications to an existing system increases. Non-standard configurations are a "***known unknown***" and should be considered in modification program planning. Successful modification programs proceed on the assumption that each system's configuration may vary from that documented. One solution (although expensive) is to audit each fielded system and "upgrade" the configuration, as necessary, to a standard baseline before proceeding with the modification.

The modification PM is responsible for the design and development of the modification. Together with the systems engineer, the modification PM assures the integrity of the existing system during and after modification. The systems engineer will assure that the developers, supporters, and users will communicate closely and continuously in order to promote a successful modification program. Communications between the user and the developer can enhance the ability of the modification to meet user needs. It can also eliminate costly rework to the system or modification kit and reduce the likelihood of adverse performance of the modified system. The modification installation schedule should be coordinated with the user to ensure that the systems are available for making the modification and that trained personnel are available to operate, maintain, and support the modified system. Effective communication channels will not guarantee successful modification programs, but they will facilitate progress toward a successful program. Modification requirements must be justified, costed, documented, funded, and accepted by the user community.

Planning and budgeting for the modification is similar to that for developing a new system. The PM must consider any required production tooling, test equipment, support equipment, simulators, and trainers; as well as, the documentation, training, and operational readiness validation for the system to be modified. Of particular importance is compatibility between different modifications, especially when incorporated separately. Problems such as electromagnetic interference could result when the total system is implemented, negating the use of one or more of the improvements. Systems engineers should analyze all proposed modifications and recommend or disapprove implementation to the appropriate Configuration Control Board (CCB) or decision authority.

16.4 SPECIAL APPLICATIONS: PRE-PLANNED PRODUCT IMPROVEMENTS

There is no single DoD specified approach to modification management. However, the Deputy Secretary of Defense, in DoDD 5000.1 [1], directed the implementation of P^3I in major DoD programs. The primary objectives of P^3I are:

a. Introduction of higher technological performance during the system's lifetime through more rapid fielding of technological advances

b. Shortening of acquisition and deployment times

c. Extension of the system's useful life (before obsolescence)

d. Reduction of system technical, schedule, and cost risk

e. Reduction of requirements for major system new starts

f. Higher operational readiness during the system's lifetime.

The P^3I concept cannot be applied to all new system developments but should be considered when:

a. A near-term need exists to build a system with current technology

b. There is a high risk that current technology will not meet a projected future threat and a low risk that future technology will not meet such a threat

c. The system can be designed to incorporate planned technology development (The most critical element is the ability to modulate the system to minimize integration and retrofit problems)

d. P^3I can be an effective means of meeting overall long term program objectives (based on threat, development risk, and total life cycle cost). It may not be cost effective for low cost, low technology systems

e. A long term military need exists for the system (P^3I can shorten the development time for the basic system; however, evolutionary changes will normally lengthen the total development period)

f. The service, DoD, and Congress demonstrate a commitment to acquire the system under the P^3I concept, including

acceptance of initially higher costs.

P^3I represents a separate and specific acquisition strategy to acquire clearly stated requirements on an incremental basis. It is not a process where the PM or the user attempts to guess future requirements and configure the basic system to accommodate these guesses. P^3I is evolutionary development or incrementalism. The mission area analysis (MAA) process results in the identification of a battlefield deficiency. The PM translates this deficiency into a specified materiel solution. When the specified solution is evaluated as ***"high risk"***, near term, reduced risk technologies are selected for the basic system in favor of parallel development of the deferred technology. Growth provisions are then designed into the basic system to accommodate future application of the higher technology. This further requirement must be clearly stated in the requirements document and validated by the user.

An example of the type of requirement that can be accommodated through P^3I is as follows: "Fire and forget preferred, but required not later than 6 years after initial operating capability," or "35 kilometer range required not later than 1995." The specific incremental capability improvement must be known in order to design appropriate growth provisions into the system. It is also needed to support the parallel development effort and the continuation of RDT&E funds past the production decision of the basic system. When this concept is not followed or is poorly understood, then goldplating results and sunk costs are built into systems, because of poor guesses. When the deferred capability is applied to the basic system, it is accomplished under the rules of standard product improvement. In addition, during the upgrade process, growth provisions are also installed to accommodate the next incremental upgrade as necessary in response to changes in the validated new future requirement. This process continues until the basic design constraints dictate a replacement system.

Figure 16-2 provides suggested criteria for choosing P^3I over a new start or a product improvement. It should be noted that no single, standardized approach can be used for every system development.

The decision to use P^3I should be made as early in the Concept Exploration/ Definition (C/E) phase as possible and no later than Milestone I. In order to make P^3I effective, the design strategy should include: 1) modular design, 2) a careful architectural interface system, and 3) provisions for space, weight, cooling, and power, for example. A development process must be established to communicate system growth requirements and identify new technological opportunities. Implementation begins shortly after the design strategy is developed, so that P^3I is incorporated into the acquisition strategy at the outset. The P^3I acquisition strategy should be communicated to industry early in the program, and industry should be included in the process of developing the strategy.

The initial request for proposal (RFP) might specify additional platform capacity, volume, or other characteristics not needed at the time of the initial configuration freeze but anticipated for later use. Further, it might specify potentially valuable modular design features in certain areas. The flexibility of the design to incorporate change

Figure 16-2
Criteria for P^3I

	P^3I	PI	NEW START
MOTIVATION FOR CHANGE	PLANNED FOR EACH UPGRADE	FORECAST LIFE OF ENTIRE SYSTEM	IN REACTION TO EVENTS
PREPARATION FOR CHANGE	R&D ON SELECTED COMPONENTS	R&D ON ENTIRE SYSTEM	SERENDIPITY -TECHNOLOGY BASE BREAKTHROUGH, NEW THREAT, OR DEFICIENCY
ORGANIZATION FOR CHANGE	REPLACE MODULE	REPLACE ENTIRE SYSTEM	COMPLEX INTERFACES MUST BE RESOLVED
DESIGN LIFETIME	DIFFERENT FOR EACH MODULE	MAXIMUM FEASIBLE FOR ALL COMPONENTS	WHATEVER IS AVAILABLE AT TIME OF PI
PERFORMANCE RELATIVE TO SOA THROUGH SYSTEM LIFE	ON AVERAGE, CLOSEST AVAILABLE SOA	HIGH AT START, ERODES AFTER DESIGN FREEZE	CATCH-UP MODE FARTHEST FROM SOA
PROCUREMENT PLAN	FOR DEFINED MODULES	FOR ENTIRE SYSTEM	AS NEEDED
CONFIDENCE IN MEETING COST AND SCHEDULE	HIGH DUE TO MANAGEABLE NO. OF CHANGES	POOR YIELD DUE TO LARGE NO. OF SUBSYSTEM CHANGES	IS OFTEN IN RESPONSE TO PREVIOUS FAILURE TO MEET GOALS
CONFIDENCE IN THREAT PREDICTION	HIGHER DUE TO SHORTER TIME FRAME	POOR BECAUSE OF LONG RANGE OF PROJECTION	IN REACTION TO THREAT CHANGES
BUDGETING APPROACH	FUNDING WEDGE PROVIDED AT EARLY TIME	SPECIFIC ACTIONS FUNDED IN ADVANCE	NO ADVANCE FUNDING PROVISIONS

would then be a prominent factor in design evaluation. The ability of the offerors to propose and conduct a P^3I program would also be part of the evaluation for Concept Demonstration/ Validation (D/V) and Full Scale Development (FSD).

Designing for P^3I may increase the initial acquisition costs of the system. The costs of designing in the flexibility for P^3I should be documented and analyzed in terms of net utility for meeting long term requirements. P^3I requires a highly disciplined CM system. Strict configuration control must be applied to such areas as subsystem boundaries, space, weight, power, cooling movement, centers of gravity, electromagnetic emissions, and logistics support system. Adequate post-deployment communication channels should be established to ensure feedback of modification data to maintain current configuration status accounting.

In the initial program phases (C/E and D/V), systems engineering conducts functional analyses to define potential solutions where "add-on" capability is identified as necessary. System synthesis must consider the additive effects of these improvement requirements; e.g., will the addition of extra capabilities in a fighter aircraft cause the pilot to become overloaded and perform less efficiently if the initial cockpit design uses only off-the-shelf components?

General P^3I system designs could include provisions for:

a. Structure - Large attachment and support strength margins, or extra volume

b. Power - Excess power generation, extra power bus capability to accommodate additional batteries and alternators, or spare wires in cables (a typical retrofit wire on an aircraft passes through eight bulkheads and costs $1,000/bulkhead)

c. Cooling - Excess pump capacity, area for capability, or throat area

d. Communications - Extra radio frequency power, excess band width, or extra channels

e. Command and Control - Multiple user data bus, large computer central processing unit margin, or excess memory

f. Modular Lay-Outs - Software and hardware units partitioned into easily replaceable pieces.

A good example to illustrate this comes from the Air Launched Cruise Missile (ALCM) program. It was determined that the range of the ALCM would have to be increased; therefore, the structural strengths, supports, and internal configuration were designed to accommodate the potential increase in propellant load. When increased range requirements became achievable, no significant structural design changes were required to accommodate it. Another ALCM example is the wing (elevon) design. The elevons are designed to the current ALCM mission requirement. Knowing that the user will need to change mission profiles in the future and that the elevon design will have to change as a function of altitude and speed, the elevons were fastened to the ALCM with eight accessible bolts, rather than being permanently bonded to the structure. This simplifies both manufacturing assembly and field modification

requirements.

16.5 LESSONS LEARNED ON MODIFICATION PROGRAMS

The following are some of the more common problems associated with modification programs:

Failure to Use Below-Depot Capability - There is a tendency to accomplish all modifications at the depot level when many modifications may be more effectively and economically accomplished at lower levels.

Unreliable Modification Management Data - Records of those units already modified, status of multiple modifications on individual units, and other related data are incorrectly maintained or are missing.

Inadequate Modification Testing - The pressure for early implementation of the modifications sometimes overrides the need to adequately test new modifications. Consequently, some modifications get to the field that do not work with existing equipment or do not work at all. In either case, the situation usually requires a modification to the modification.

Installation Delays - By the time some modification kits find their way to the end item in the field, the item has been altered or was not in the expected configuration to begin with (see "Unreliable Modification Management Data," above). Therefore, installation of the modification is further delayed while a change is obtained so that the installation may be accomplished.

Inadequate Kit Accountability and Control Procedures - Bulk purchases of modification kits to be installed over an extended period of time expose the stored kits to cannibalization, pilferage, and other loss.

Difficulties in Integrating Changes - Poor communications between user, developer, and supporter lead to mismatches between modification design, end item design, and user needs. This makes integration one of the biggest single problems with modification programs.

Inadequate Support Planning - There is a tendency to overlook how a modified system will be supported and how multiple configurations of a system will be supported until all modifications are installed.

16.6 DOCUMENTATION: SYSTEM MODIFICATION PLAN

Preparation of a modification plan is a service peculiar process. Essential elements of the modification plan should include:

a. Purpose of the modification - impact on system effectiveness

b. Description of modification - power, weight, volume, data interface

c. Identification of items to be modified - type, location, configuration status, availability

d. Strategy for implementation - schedule, modification, phasing

e. Organizational responsibilities - lines of communications, CM, data generation

f. Logistics support - packaging, handling, transportation, and storage (PHST), training,

manuals, and supplies.

16.7 REFERENCES

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CHAPTER 17

LIFE CYCLE COST

17.1 INTRODUCTION

Life cycle cost (LCC) is the total cost to the government of acquisition, ownership, and disposal of a system over its entire life. During the Concept Exploration/ Definition (C/E) phase, the LCC effort is focused on identifying cost drivers, evaluating **relative** LCC differences among competing alternative concepts, and developing the estimate(s) supporting the System Concept Paper (SCP) supporting Milestone I. During the Concept Demonstration/ Validation (D/V) phase, the LCC emphasis is on developing a LCC estimate for each alternative. During Full Scale Development (FSD), the LCC baseline cost estimate established in D/V must be refined. In FSD, LCC begins its transition from primarily a design element to a control element for the program. All decisions should still be considered in light of their effect on LCC, but, at this point in development, LCC is more of a control tool for keeping the program on track by highlighting the effect that decisions and changes will have on total program cost. LCC is used in Operation and Support (O&S) to consider the impact of modifications, value engineering proposals, and product performance agreements.

DoDD 4245.3 [1] is the principal policy statement on cost. The directive states that cost is ***"a parameter equal in importance to technical and supportability requirements and schedules."*** The directive calls for designing for lower LCC by establishing cost goals and thresholds based on credible acquisition and O&S cost parameters that are consistent with program plans and budgets and that achieve the best balance among cost, schedule, performance, reliability, and supportability characteristics. Measurable and achievable design to cost (DTC) goals and thresholds must be established at Milestone II.

Historically, a low initial acquisition cost for hardware has not assured a low LCC. In fact, the opposite is true. The bulk of LCC is usually in O&S costs, as shown in Figure 17-1. The majority of system costs is typically in the operations and support area. Since there are always alternative concepts and design for system support, there is a need to assure that the accepted concept and design will not have excessive O&S costs. This sometimes means spending more on research and development to improve reliability or maintenance access. The timing of that effort, and the relative impact on LCC however, is sensitive to the evolution of the design.

Figure 17-2 depicts the opportunity for reducing costly design concepts. As illustrated by the figure, efforts to minimize life cycle costs are most effective in the conceptual and early design stages when alternatives are being identified and selected. By Milestone I, roughly 70 percent of a

Figure 17-1
Nominal Cost Distribution of a Typical DoD Program

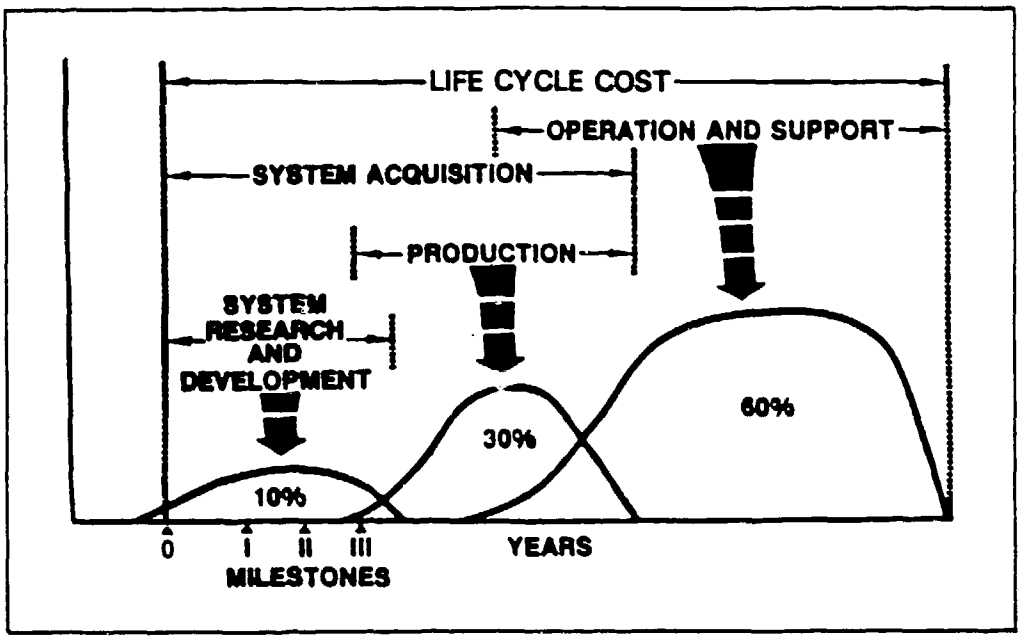
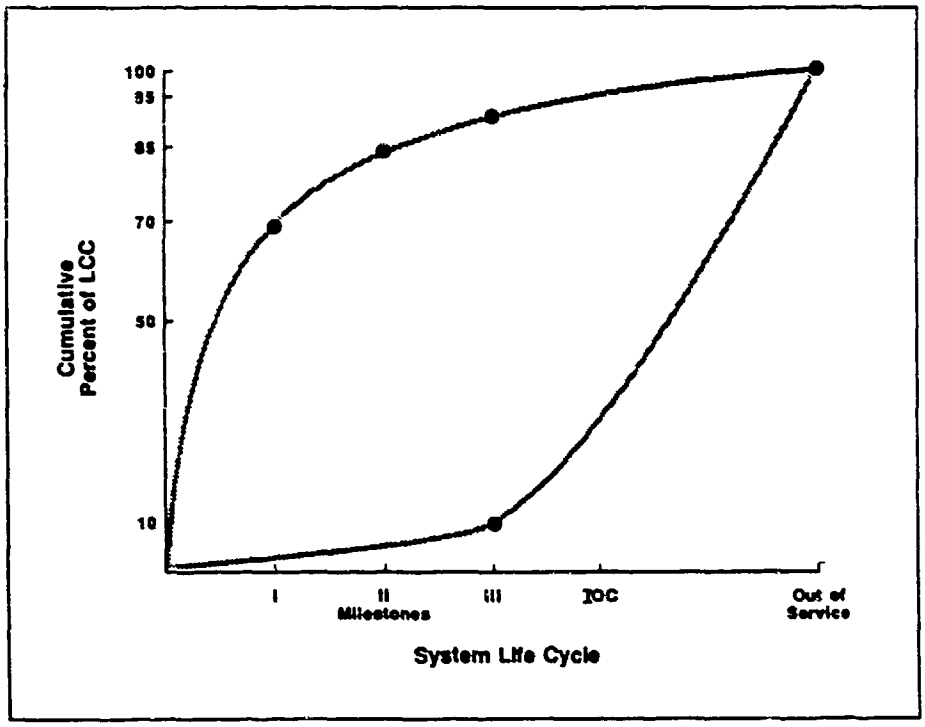


Figure 17-2
Effect of Early Decisions on Life Cycle Cost



system's LCC is "locked in" by design decisions, while less than 5 percent of its LCC has actually been expended.

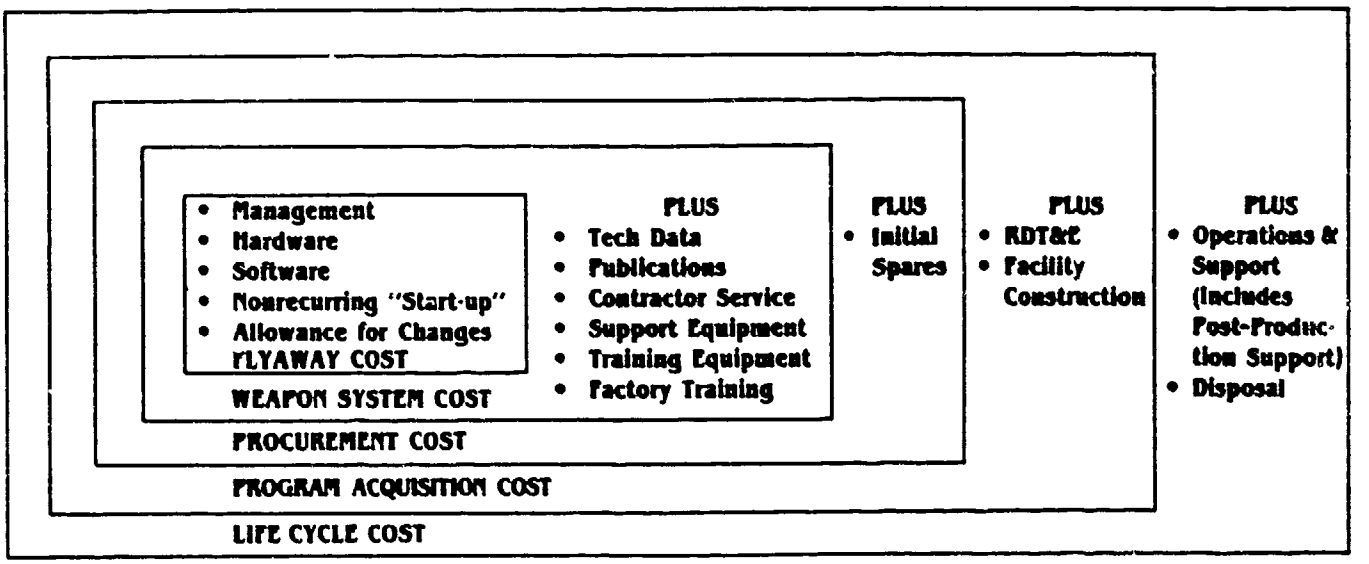
Although the military budget has remained relatively flat (in constant dollars) during the past 30 years, O&S costs have grown during that period at a rate greater than three percent per year (constant dollars). During this period, the military budget has steadily declined as a percentage of gross national product. This implies that the greatest potential opportunity for cost reduction in the Department of Defense (DoD) lies in controlling the high yet invisible cost of system support.

17.2 APPROACH

Within life cycle cost, there are several well-defined cost components, as shown in Figure 17-3. One used often between the Program Manager (PM) and the industry contractor for cost control is "flyaway", "sailaway", or "rollaway" cost. This is the cost of procuring the basic unit, average changes allowance, cost allocated to the basic unit, propulsion equipment, electronics, armament, other installed government furnished equipment (GFE), and nonrecurring production. Warranty coverage is also included. These categories are defined in DoDI 5000.33 [2].

Costs for support equipment required to operate in the field, costs for data, and costs for training, when added to flyaway (sailaway or rollaway) cost, make up "weapon system" cost. PROCUREMENT cost increases beyond weapon system cost to include the initial spares. Procurement cost added to the cost of research, development, test, and evaluation (RDT&E) and facility construction costs, makes up "program acquisition" cost, even if the cost for facilities is not in the program office budget. The total of all of

Figure 17-3
Life Cycle Cost Composition



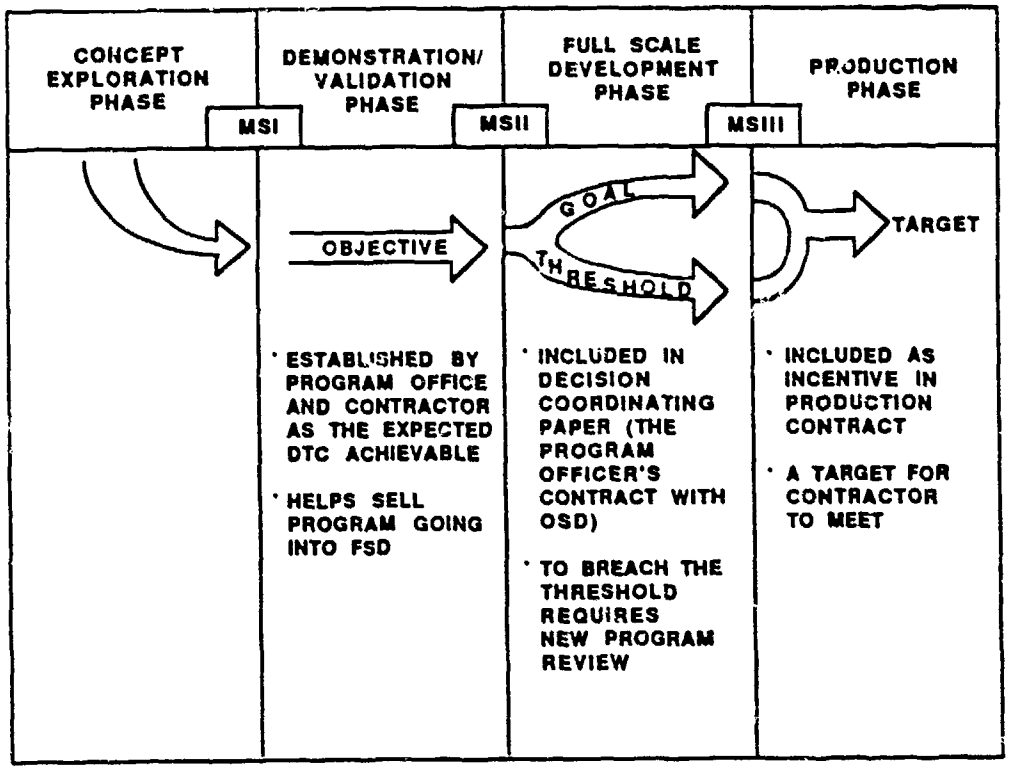
these costs, including the cost of operation, support, and eventual disposal, makes up life cycle cost.

Specific terms are used to refer to various cost elements. Figure 17-4 displays these cost terms by program phase. Prior to Milestone II, the program office and contractor establish a cost objective for the program in terms of achievable design to cost values. During FSD, the objective becomes a firm goal and not-to-exceed threshold that the program office accepts in the Decision Coordinating Paper (DCP). The goal and threshold are translated into a target for the contractor with award of the Milestone III production contract.

17.3 ESTABLISHING COST GOALS

A design to cost program is an important subset of the LCC concept. It requires a system to be designed and built within specific cost goals, both for average unit flyaway cost and O&S cost parameters. A DTC program seeks to balance unit production costs against ownership costs during development while decisions can still be implemented. The Joint Design to Cost Guide [3] states that DTC/LCC should be applied early in the development cycle, when the design may be heavily influenced through requirements generation. Just prior to FSD, DTC/LCC provides information upon which to base decisions for alternative concepts and

Figure 17-4
Cost Terms by Program Phase



designs. A flyaway (sailaway or rollaway) cost goal is established by the program office based on such factors as budgetary constraints established by Congress, service budgetary constraints, independent cost estimates, economic forecasts, prior concept exploration studies, etc. A certain portion of flyaway cost is allocated to the contractor as the goal for unit production cost. The program office will retain the remainder of the flyaway cost to cover internal DoD investment costs and engineering change allowances.

Per Reference [3], application of cost goals in FSD is mandatory, since FSD is the last opportunity to significantly influence the design before production. It is essential that the selected cost goals can be related directly to the LCC estimates that support the DCP at the Milestone II review or budget submittals. The average unit flyaway cost objective becomes a firm DTC goal after Milestone II. Firm goals and thresholds for O&S parameters must also be established at Milestone II. Selected O&S parameters (e.g., reliability and maintainability) should represent factors that significantly affect O&S costs, are design controllable, and can be measured during test and evaluation.

DTC goals should be established from a knowledge of cost improvement potential for the system, together with projected budgetary limitations. The key to achieving DTC goals is flexibility in allowing the designer freedom of choice and decision to arrive at a configuration that satisfies mission objectives. This can be achieved through contracts and specifications that:

a. Specify the performance needed, not the way to obtain the result

b. Specify a total time to operational capability, not detailed interim milestones

c. Schedule a program permiting several iterations, not on a 100 percent success basis for the first attempt.

DTC goals should be achievable. If the goal is too easily achieved, there is no motivation toward cost reduction through critical examination of requirements, concepts, and designs. This may result in acquiring incremental performance or design features that are not cost-effective. Conversely, if the goal is too difficult, motivation is destroyed because no amount of ingenuity on the part of the contractors to use advanced technology or simplified designs could be expected to achieve the goal.

17.4 COST ESTIMATING PROCEDURES

LCC may be estimated using any of a number of estimating techniques. The cost estimate evolves and is refined as the program matures. This is illustrated in Figure 17-5. The source and type of the cost estimate are usually dependent on the certainty of the cost elements. The following estimating techniques are most commonly used:

a. Parametric analysis

b. Analogy

c. Bottom-up or engineering

d. Other (best guess, Bayesian Statistics/Delphi Process).

Figure 17-5
Cost Estimating Methods and Most Prevalent Use by Acquisition Phase

	CE	D/V	EARLY FSD	LATE FSD	PRODUCTION
PARAMETRIC	P	S	S	NA	NA
ANALOGY	S	P	S	NA	NA
BOTTOM-UP/ ENGINEERING	NA	S	P	P	P

P = PRIMARY METHOD(S)
S = SECONDARY METHOD(S)
NA = NOT NORMALLY USED

On large programs, all of these approaches may be used to provide an estimate of costs. However, bottom up estimating is labor intensive and time consuming. Parametric analysis can be done very quickly (in a matter of days) and correlates closely with estimates generated using the bottom up method (usually within two to three percent). The analogy method is generally used to calibrate results of the parametric analysis. Note that the "best guess" is not intended to be a guess for the total system cost. Frequently, estimating the cost for a component where no precedent data are available requires an educated guess.

17.4.1 Parametric Analysis

A broad existing data base gathered from hardware and software developed for similar purposes can be manipulated by a computer to establish a price, using only a minimum number of characteristics (such as weight and size). Several computer based parametric models are available to perform cost analysis, as shown in Figure 17-6. However, the RCA PRICE (Programmed Review of Information for Costing and Evaluation) model has by far the widest use and is now employed by the Air Force, Army, Navy, NASA, aerospace companies, many commercial organizations, and several foreign governments, to provide cost estimates.

17.4.2 Analogy

Where the new item has functions and physical and performance characteristics similar to an existing item, current costs on

Figure 17-6
Cost Estimating Models

USAF PROGRAMS	USN PROGRAMS	US ARMY PROGRAMS	DSMC PROGRAMS
• LOGISTICS SUPPORT COST (LSC) • AD LCC MODEL • AFLC LCC MODEL • CONTRACTOR MODELS	• LIFE CYCLE COST (LCC) SYSTEM • LIFE CYCLE COST EQUIPMENT • CONTRACTOR MODELS	• GENERALIZED ELECTRONIC MAINTENANCE MODEL (GEMM) • LOGISTICS COST ANALYSIS MODEL (LOCAM 5) • CONTRACTOR MODELS	• CASA • QUICK REACTION MODEL (DPESO) • SCHEDULE & COST MODEL (VERT)

the similar item can be gathered and modified appropriately to account for the difference in configuration.

17.4.3 Bottom Up

Each organization and group involved in the development and production of an item estimates its costs. The results are totaled and combined with overhead, general and administrative expense, and contract fee to arrive at an estimate for the item. Based on a preliminary equipment list, test concepts, and a Manufacturing Plan, the cost of hardware items is established for development and production. Lines of code are estimated based on the identification and definition of software modules. Software costs can then be established for development and testing. Operational costs and costs associated with spares, support equipment, training, data, operating personnel requirements, and supplies and material for the prescribed operational period are also defined. The aggregate of these costs is the cost to develop and field the entire system.

17.5 LCC ANALYSIS

LCC analysis is the structured study of LCC estimates and elements to identify life cycle cost drivers, total cost to the government, cost risk items, and cost

effective changes. It is a systems engineering tool with application to all elements of the system.

Computer modeling is often used to identify and analyze life cycle cost drivers. Cost drivers are parameters that control O&S costs such as reliability, maintainability, parts, and support equipment, to name a few. Cost drivers are areas where resources can best be applied to achieve the greatest benefit in reduced costs. For example, a reduction in manpower requirements would have a significant effect on a system's LCC. An effective LCC analysis will identify areas where contract incentives may be applied to earn the greatest pay-off.

Modeling for LCC is also useful in cost benefit and cost effectiveness studies, long-range planning and budgeting, comparison of competing systems, decisions about replacement of aging equipment, control of an ongoing program, and selection among competing contractors.

Many computer models are available, but no single model suits every application. Reference [4] offers models, calculations, and formulas (cost estimating relationships) appropriate to each phase of the acquisition cycle. Reference [5] evaluates several Air Force computer models for aviation systems. The Defense Systems Management College (DSMC) has three new models that can be run on a personal computer: 1) a LCC model, CASA (with a risk model); 2) a quick reaction model, DPESO; and 3) a schedule and cost risk model, VERT. Each of the models provides a means for examining cost impact.

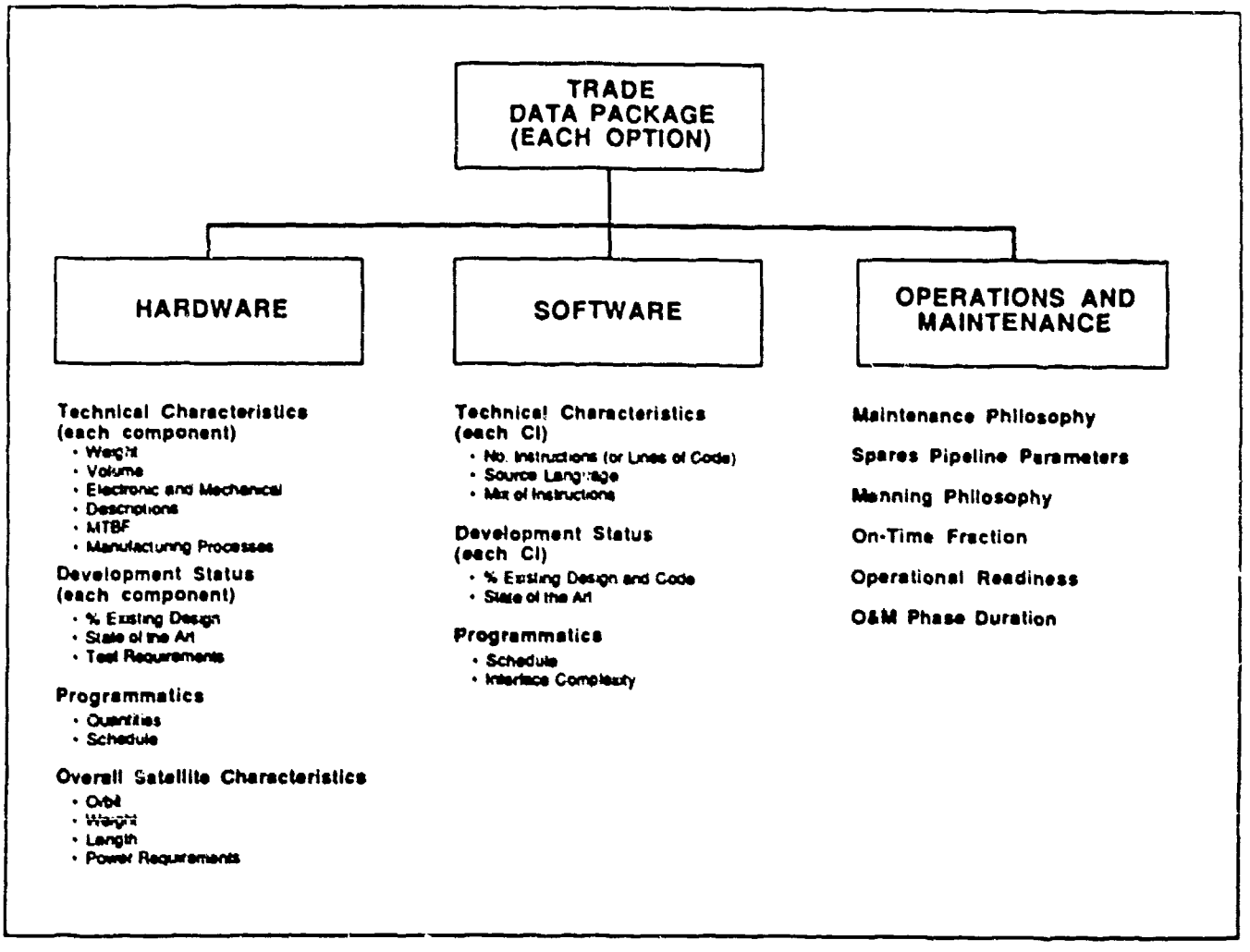
17.6 APPLICATION OF TRADE-OFF ANALYSES TO LCC/DTC

LCC trade-off analyses are employed to obtain an optimum balance between cost and effectiveness. The trade-off analysis method is discussed in Chapter 8 of this guide. Potential input variables for LCC trade-off analyses are shown in Figure 17-7. As an example, microprocessors could be incorporated into the design to automate functions and provide for built-in-test (BIT). This would increase development cost (due to software development) but could reduce weight, size, and maintenance costs with a potential overall cost reduction. In considering total LCC, reliability and maintainability have a major impact since the system and subordinate level unreliability reflect directly on required logistic support in terms of skills and levels of maintenance personnel required, spares stackage, personnel training, and their effect on operation and maintenance (O&M) cost.

The DTC trade-off analyses take into consideration the variables of reliability and maintenance at some sparing level, and the DTC aspects of each trade-off candidate. At one extreme, a highly reliable system may represent a high order, front end investment. This investment will be reflected through all subordinate system elements of hardware and software. At the other extreme, candidates of nominal reliability represent a far lower investment, but may be expected to incur higher logistics and maintenance costs in end-use service. The DTC objective is set at the optimum point between these extremes.

As part of the maintenance trade-off

Figure 17-7
Trade-Off and Input Variables



analyses, the following variables may be examined to establish cost drivers:

a. Number of equipment level maintenance and/or supply locations

b. Number of organization, intermediate, and depot level maintenance locations

c. Number and level of skills required for support

d. Duration of the support period

e. Equipment operating time

f. Number of line replaceable units (LRUs), modules, and parts

g. LRU mean time between failure

h. LRU and module mean time to repair

i. Amount and quality of built-in-test equipment (BITE)

j. Cost of contractor repair

k. Test equipment costs

l. Spares and test equipment storage space requirements

m. Production learning curves

n. Safety stock coefficients

o. Resupply times

p. Crew size and labor rates

q. Cost of entering and maintaining items in the supply system

r. Cost of programming and documenting test equipment

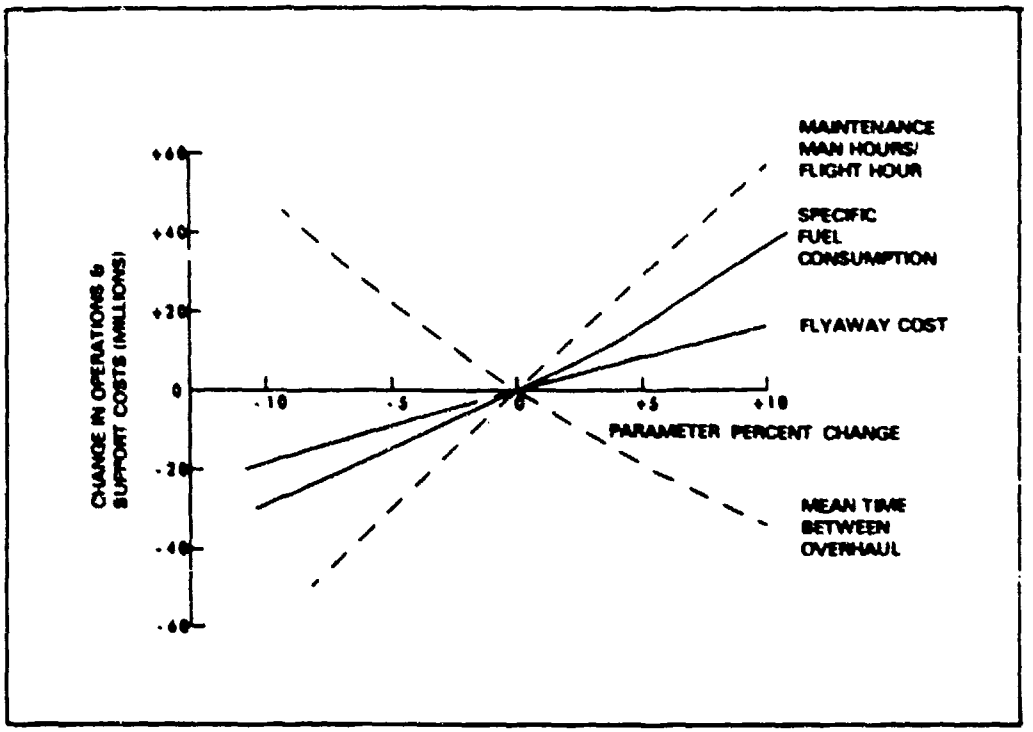
s. Dedicated versus non dedicated crews.

Sensitivity studies are conducted to identify areas where resources can best be applied to achieve the maximum cost benefit. These studies examine performance parameters to determine where small changes in the parameters would produce significant changes in development and operational costs. In the example shown in Figure 17-8, a relatively small change in maintenance manhours per flight hour or mean time between overhaul results in large savings in operational costs.

17.7 DOCUMENTATION

It is the PM's responsibility to ensure that the contractor establishes and carries out a LCC program. An assessment of how well the LCC program is implemented should be made during program management reviews

Figure 17-8
Cost Sensitivity Study Results for an Aircraft Program



and technical reviews, and prior to key program demonstration milestones. During program management reviews, the contractor should be tasked to address: 1) life cycle cost implementation plans and the status of key activities; 2) cost drivers and actions taken or actions planned to reduce or control costs; 3) the status of cost-related design goals; and 4) trade-off analyses planned, ongoing, or recently completed.

Supporting documentation for the contractor's program is provided in the Life Cycle Cost Plan (LCCP). The contractor's LCC estimate, associated Trade Study Reports (TSRs), and cost related design goal status data should also be reviewed by the program office.

17.7.1 Life Cycle Cost Plan

The LCCP, as required by MIL-STD-499A [6], is developed by the contractor to describe the approach for integrating LCC into the management and design effort. The plan should address the following issues (as recommended by Reference [4]):

a. On what ground rules and assumptions should the LCC analysis be based?

b. Which estimating procedures will be used?

c. What kind of product is the LCC analysis to produce, for whom, in what format, and for what purpose?

d. How will buyer and seller audit and control the LCC process?

e. How will the LCC effort be organized and financed?

Recommendations for content of the LCCP, as defined by data item description DI-F-30203 [7], include the following:

a. Statement of the contractor's LCC management objectives and a description of supporting tasks, milestones, and responsibilities

b. Program structure, policies, procedures, and functional relationships for maintaining LCC visibility and control

c. Method(s) for determining and identifying LCC drivers and issues subject to trade-off analyses

d. Preliminary list of the 10 most influential contract requirements that affect the LCC of the system (e.g., performance, schedules, standards, specifications)

e. Description of planned analysis methods and DTC/LCC modeling techniques to be used in LCC analysis

f. Management approach for integrating subcontractors' effort into LCC management efforts

g. Recommended LCC/DTC goals and planned allocation procedures

h. Planned feedback mechanism for tracking and supporting cost related design goals and status, including proposed analysis, test, and evaluation efforts to be used as progress checks.

17.7.2 Life Cycle Cost Estimate

The contractor should provide a LCC estimate that will serve as a cost baseline for the program. The documentation of this estimate should include:

a. Purpose and scope

b. System and program description summary

c. Program schedule summary

d. Ground rules and assumptions

e. Summary estimates for RDT&E, production, and O&S costs

f. Rank ordered list of systems/ components/ software, which account for not less than 80 percent of the total estimated system LCC

g. RDT&E estimate by work breakdown structure (WBS) element and function

h. Production estimate by WBS element and function

i. O&S cost by WBS element and function

j. Time-phased program costs

k. Funding spreads

l. Inflation and discounting methodology and indices

m. LCC estimate tracking

n. sensitivity analyses

o. Risk and uncertainty analysis of each WBS level.

Adequate documentation requires three basic elements: 1) the data and sources of data on which the estimate is based, 2) the estimating methods applied to that data, and 3) the results of the analysis. The main thrust of any documentation package is methodology. Parametric equations, learning curves, cost performance analyses, and factor derivations or build-up techniques for each part of the estimate are described to provide continuity and consistency and to facilitate tracking for future estimates. An estimate track consists of a comparison to prior estimates and an analysis of reasons for differences. The explanation of differences should be quantitatively expressed, if possible.

17.7.3 Engineering Trade Study Report

An engineering Trade Study Report documents the trade-off analyses conducted to achieve cost goals. It should describe the analysis methods and their adequacy, identify data sources and degree of confidence in the accuracy of the data, and define alternatives and the rationale for selection. Cost drivers should be defined and areas for future trade-off analyses identified.

17.7.4 Cost-Related Design Goal Status Data

Design goal status data are produced during the FSD phase and used to measure performance toward achieving the cost related design goals, and to provide projections and analyses necessary to develop timely management decisions concerning trade-off and design changes. For the unit production cost goal, status information is

normally provided at the summary WBS level and for each specified WBS element in terms of hours and dollars for each functional cost (e.g., engineering, tooling, manufacturing, quality control, and purchased equipment) for recurring and non-recurring cost. For non-dollar, cost related design goals such as crew size, maintenance manpower, and operational reliability and maintainability parameters, the status reporting should address the current value (planned and achieved) and the mature value (goal and current estimate) and variances. The rationale for variances that exceed a specified amount or percent and schedule for corrective action should also be provided.

17.8 REFERENCES

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5. "An Appraisal of Models Used in Life-Cycle Estimation for United States Ai Force Aircraft Systems", DTIC Technical Report, Defense Logistics Agency, October 1978.

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7. DI-F-30203, "Design to Cost/ Life Cycle Cost Reports".

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9. AFR 800-11, "Life Cycle Costing".

10. OMB Circular A-76, Supplement 1, "Cost Comparison Handbook".

11. DAP 11-2, "Research and Development Cost Guide for Army Materiel Systems".

12. DAP 11-3, "Investment Cost Guide for Army Materiel Systems".

13. DAP 11-4, "Operating and Support Cost Guide for Army Materiel Systems".

14. DAP 11-5, "Standard for Presentation and Documentation of Life Cycle Cost Estimates".

15. Army Force Planning Handbook TTO-ORT-037-76B-V3, "Life Cycle Costing, Joint Tactical Communication".

16. AFSC/AFLC Joint Command Working Group on LCC, "Life Cycle Cost Procurement Guide".

17. AR 70-64, "Design to Cost".

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CHAPTER 18

MANUFACTURING AND PRODUCIBILITY

18.1 INTRODUCTION

One conclusion that may be drawn from DoDD 4245.7 [1] is that production management is a system management job. It is no accident that published descriptions of the systems engineering process since the early 1960s have included the production function as an integral part of the system life cycle. Failure to consider production requirements early in the acquisition cycle has resulted in more than acceptable risk in the transition from development to production. As pointed out in the Department of Defense (DoD) study [2], ***"The acquisition process (should be) recognized for what it is ... an industrial process concerned with the design, test, and production of low risk products"***. Product design and development cannot be logically separated from the production process. The approach taken to design most often radically constrains the producibility of a product. It is for this reason that producibility attributes should be an integral part of all configuration item trade studies.

Once production is viewed as simply another life cycle function, not unlike companion operation and support functions, then systems engineering tools can be used to manage the production process. The timely application of systems engineering tools and the systems engineering process can contribute to assisting industry in achieving higher levels of productivity.

The capability to produce a hardware item that satisfies mission objectives is as essential to the systems engineering process as other functions such as operations or support. The application of the systems engineering process to production functions will identify the products required to transform design into a capability for efficient and economical production of equipment and facility elements of the system. Systems engineering also ensures that production capabilities are constantly used as design selection criteria. Typical production functions that will be analyzed during a fully integrated design effort include such actions as material ordering, material handling, fabrication, processing, quality assurance, process control, assembly, inspection, test, preservation, packaging, storage, shipping, and disposition of scrap, salvage, and waste materials. All of this analysis is best done under the Total Quality Management (TQM) umbrella.

The systems engineering process applied to production functions supports producibility analyses, production engineering inputs to trade studies, life cycle cost analyses, and consideration of the materials, tools, test equipment, facilities, personnel, software, and procedures that support manufacturing

Figure 18-1
Manufacturing Activities in the System Acquisition Process

Concept Exploration/ Definition Phase
- .Evaluate Production Feasibility
- .Assess Production Risk
- .Identify Manufacturing Technology Needs
- .Identify Manufacturing Cost
- .Develop Manufacturing Strategy
- .Identify Deficiencies in U.S. Industrial Base
- .Determine Availability of Critical Materials
- .Develop Contract Requirements for D/V Phase
- .Begin Value Analysis Studies

Concept Demonstration/ Validation Phase
- .Assess Producibility of Competitive Designs
- .Accomplish Production Risk Resolution
- .Reassess Production Transition Risk
- .Evaluate Producibility Criteria
- .Plan for Achieving Producibility
- .Assess Production Feasibility
- .Complete Manufacturing Technology Developments
- .Plan for Use of Competition in Production
- .Develop Initial Manufacturing Plan
- .Evaluate Long Lead Procurement Requirements
- .Develop Initial Manufacturing Cost Estimate
- .Develop Production Readiness Review Plan
- .Develop Contract Requirements for FSD Phase
- .Continue Valua Analysis/ Engineering Efforts

Full Scale Development Phase
- .Evaluate Producibility of Design
- .Revise Production Risk Evaluations
- .Define Required Manufacturing Resources
- .Develop Detailed Production Design
- .Define and Proof Manufacturing Processes and Equipment
- .Accomplish Producibility Engineering
- .Accomplish Production Planning
- .Integrate Spares Production
- .Develop Production Work Breakdown Structure
- .Develop Manufacturing Cost Estimates
- .Complete Manufacturing Plan
- .Plan for and Accomplish System Transition
- .Accomplish Production Readiness Reviews
- .Develop Contract Requirements for Production Phase
- .Complete Initial Production Facilities
- .Solidify Production Baseline/ Limit Engineering Changes

Production and Deployment Phase
- .Execute Manufacturing Program
- .Maintain Production Surveillance
- .Implement Product Improvements as planned for in FSD
- .Provide and Support Government-Furnished Property
- .Accomplish Further Value Engineering (e.g., on P3I, processes)
- .Accomplish Second Sourcing/Component Break-Out
- .Complete Industrial Preparedness Planning

in the Concept Demonstration/ Validation (D/V) and Production phases. For example, critical producibility requirements are identified early and incorporated into the program risk analysis. Where the production functional analysis identifies requirements creating a constraint on the design, they are included in applicable development and product specifications and/or engineering drawings. Programs involving an evolutionary upgrade as well as higher risk efforts should infuse the producibility process as early as concept exploration.

This chapter describes the tools and procedures with which production engineering, as an integral part of the systems engineering "team," interacts with designers to ensure that the resulting design represents the most producible design with acceptable cost and schedule risk. Production engineering is defined in the Defense Systems Management College (DSMC) Program Manager's (PM) Notebook as the application of design and analysis techniques to produce a specified product, including:

a. The functions of planning, specifying, and coordinating the application of required resources

b. Performing analyses of producibility and production operations, processes, and systems

c. Applying new as well as existing manufacturing methods, tools, and equipment

d. Controlling the introduction of engineering changes so that they are almost non-existant by Milestone III startup

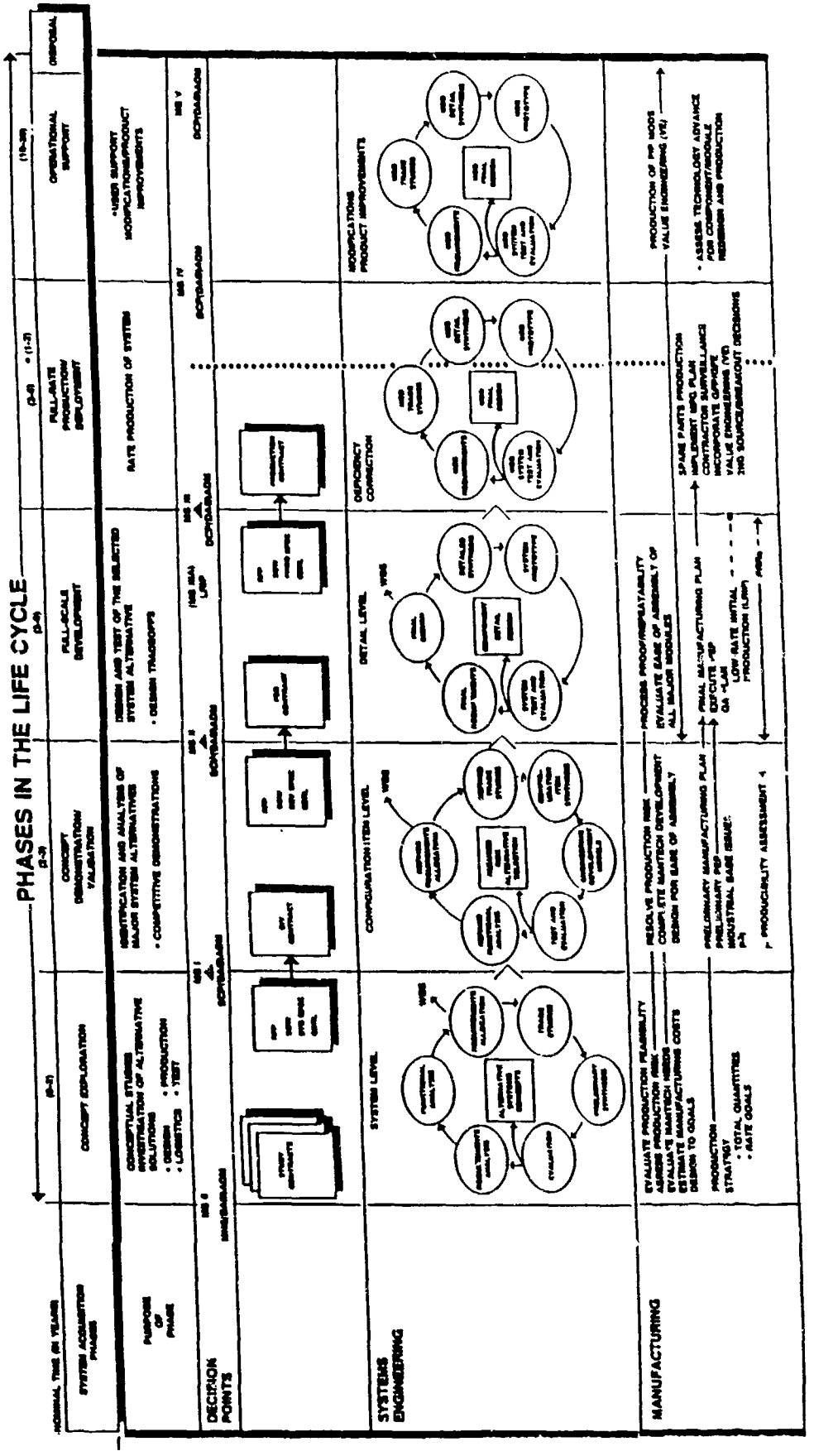
e. Employing meaningful cost control techniques.

18.2 APPROACH

Manufacturing activities begin in the Concept Exploration/ Definition (C/E) phase when a system concept has been defined. Initial activities are concerned with production feasibility, costs, and risks. Prior to Milestone I, DoDI 5000.2 [3] requires that an industrial resource analysis (IRA) be conducted to determine the availability of production resources required to support a major system production program. These resources include capital, material, and manpower required to accelerate and maintain full production ratios and respond to surge and mobilization requirements. The IRA would include results of feasibility studies, producibility analyses, and manufacturing program and producibility assessments. As development proceeds, trade studies and preaward surveys are conducted to establish the most cost-effective methods for manufacturing items, and detailed plans are developed for the Production Phase. Prior to Production, extensive controls are implemented at both prime contractor and subcontractor facilities to ensure that the product will meet specifications. Producibility analyses may generate the need for a requirements scrub effort by the PM and user during the C/E or D/V phases.

MIL-STD-499A [4] describes a basic systems engineering process which details

Figure 18-2
Production/Systems Engineering
Life Cycle Relationships



many activities that support production engineering, producibility engineering and planning, production risk management, and general integration of production requirements within the engineering management process. Requirements and options for production rates and quantities are elemental drivers of the systems engineering controlled design process.

The requirements for contractor production management are given in DoDD 4245.6 [5]. It defines the need to establish:

a. Industrial resource analyses

b. Production Readiness Reviews (PRR)

c. Production risk analysis

d. Manufacturing strategy

e. Comprehensive producibility engineering and planning program

f. Effective integration with the quality program

g. Independent assessment of production readiness

h. Planning for post-production activity

i. Incorporation of a variety of cost avoidance and/or reduction techniques

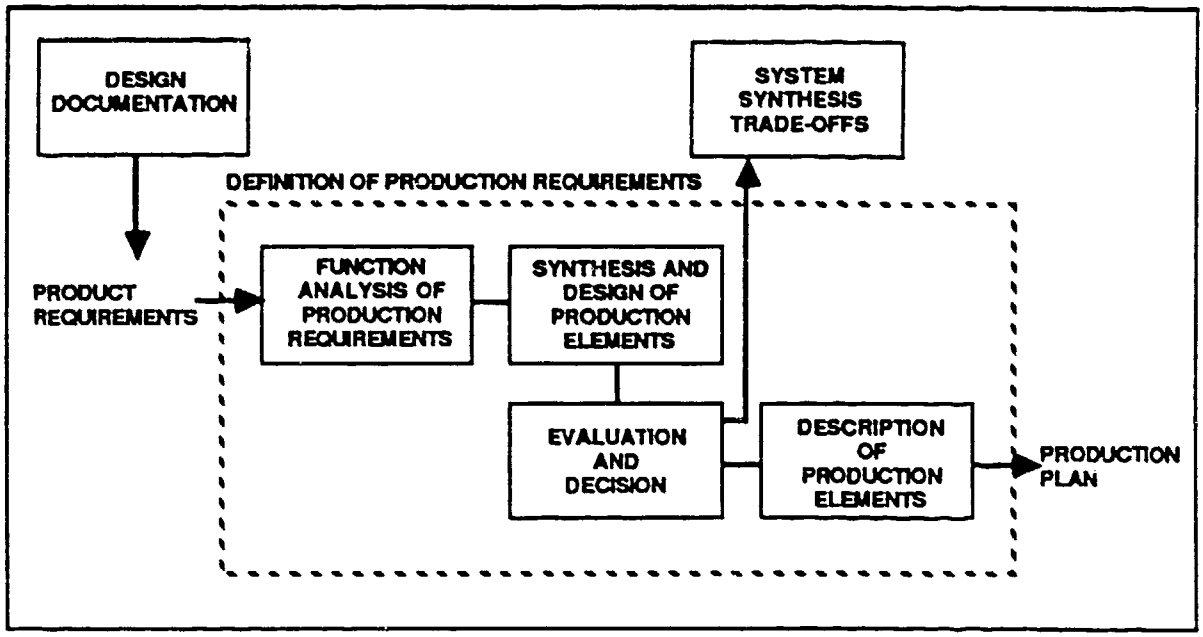
j. Emphasis on life cycle cost.

The risk management templates of DoD 4245.7-M [2] are designed to permit ease in the management of the systems engineering process so that it ensures low-risk production. The templates are to be used as a guide and tailored to the individual production programs.

During the early program phases, the contractor's production engineering personnel must be integrated into the systems engineering organization to ensure that producibility requirements are incorporated into the basic systems engineering documentation, specifications, and plans. The production engineers review conceptual designs together with other engineering specialists, conduct manufacturing trade studies to establish the most producible design, identify required production resources, and prepare the Production Plan.

During the Full Scale Development (FSD) phase, a manufacturing organization is established if not already in place for other programs. The elements of production engineering, product assurance, planning, facilities, and production equipment are often integrated into the organization. Product assurance provides process control of manufacturing and subcontractor operations under the Total Quality Management umbrella. Prototype and qualification articles are produced and tested to demonstrate that the system meets its specification requirements. Prior to the start of full production, Production Readiness Reviews are conducted to assure that all necessary resources and controls are established and all action items are closed prior to MS III. Depending on the size and complexity of the system, a PRR may be held as a single review or as a series of

Figure 18-3
Basic Production Systems Engineering Process



reviews.

18.3 PRODUCTION ENGINEERING ANALYSIS

Production engineering analysis begins in the C/E phase, as stated in MIL-STD-499A [4], MIL-STD-1528 [6], and DoDD 4245.6 [5]. This analysis requires rate and quantity inputs that may themselves be the products of major trade-off analysis efforts. Typically, the production engineering analysis is performed as a team effort to:

a. Establish estimates of the production capability required

b. Assess previous production and user experience and problems encountered on similar programs in conjunction with cost/ schedule control system (C/SCS) reporting

c. Identify, develop, and document new technology or special processes

d. Assess production feasibility and identify risk areas including use of the GIDEP Reports.

e. Develop production costs and schedules

f. Define production risk mitigation approach and associated milestones

g. Define tooling requirements with worker involvement

h. Define a production test plan

i. Establish inspection requirements with worker involvement

j. Establish personnel skills and training

requirements

k. Evaluate existing facilities and equipment to establish any modifications or new resources for manufacturing

l. Develop a manufacturing assembly sequence chart

m. Define and implement producibility criteria into the technical data package

n. Identify trade areas to reduce risk or cost.

The objective of the production engineering analysis, considered as an integral part of the systems engineering process, should be to permit the production of a quality system (which meets the user's needs) on-time, at the lowest possible cost. The basic systems engineering process has the tools and documentation to effect definition and development of system elements (equipment, software, personnel, procedures) related to production functions and production requirements.

During the early program phases, production engineers work with systems engineers to define the impact on existing resources and provide data on manufacturing alternatives to proposed designs using the basic systems engineering process.

18.4 PRODUCIBILITY TRADE STUDIES

Manufacturing trade study areas include engineering design, reliability, maintainability, program schedules, life cycle cost, effectiveness, producibility, supportability, and other factors affecting overall program objectives. Trade studies are conducted to evaluate the most cost-effective manufacturing process to be employed within program constraints. The trade study process involves the identification of alternate candidates, definition of evaluation criteria, weighting and scoring of the candidates, and examination of adverse consequences. Through analysis and gathering of data, the characteristics of each alternative will be established. The candidates will then be scored and the results summarized in the trade table.

18.5 MANUFACTURING PLANNING

The results of the production engineering analysis are documented in the Production Plan, which defines manufacturing concepts and methods. The Production Plan MIL-STD-1528 [6] provides sufficient information to supporting organizations to assure a timely, coordinated approach to the production process. The plan is developed in preliminary form during the C/E and D/V phases and is part of a CDRL. The final plan is completed prior to the PRR effort. An outline of the plan is provided in Section 18.7. During the FSD phase, as the detailed design is completed and prototype hardware is developed, production engineering supports planning by continuing to refine its analyses to more detailed levels and by developing requirements for items not visible in earlier phases, such as shop aids or templates that could optimize production and assembly. After the baseline design is established, engineering change proposals (ECPs) are evaluated by production engineering as part of the configuration

Figure 18-4
Reflector Fabrication Trade Table

METHOD	MATERIAL	ADVANTAGES	DISADVANTAGES	PROBLEM AREAS	RANK
I METALLIC FACE PLATE, COMPOSITE REINFORCEMENT	ALUMINUM MAGNESIUM	○ LIGHT WEIGHT	○ CANNOT STRESS RELIEVE METALS ○ REQUIRES AIR CONDITIONED POD (MATERIAL EXPANSION) ○ REQUIRES SPECIAL MILL RUN MATERIAL LENGTHS	○ MEASUREMENT TECHNIQUES NEED DEVELOPMENT ○ RETAINED STRESSES WILL WARP ASSEMBLY DURING FINAL GRINDING ○ EXCESS LENGTH WILL REQUIRE MACHINE MODIFICATION TO GRIND FLATNESS	3
	TITANIUM	○ MODERATE WEIGHT ○ STRESS RELIEVABLE ○ GOOD STIFFNESS	○ REQUIRES AIR CONDITIONED POD ○ SPECIAL MILL RUN MATERIAL LENGTHS ○ TITANIUM NOT A GOOD CONDUCTOR	○ REQUIRES HOT VACUUM BOX FACILITY TO FORM CONTOUR ○ SAME AS ABOVE EXCEPT FOR RESIDUAL STRESSES	
II METALLIC FACE PLATE, METALLIC BACK-UP CONSTRUCTION	ALUMINUM MAGNESIUM	○ LIGHT WEIGHT	○ SAME AS ABOVE ○ ASSEMBLY SHIMMING IS REQUIRED	○ SAME AS (I) ALUMINUM	4
	TITANIUM	○ MODERATE WEIGHT ○ STRESS RELIEVABLE ○ GOOD STIFFNESS	○ SAME AS (I) TITANIUM	○ SAME AS (I) TITANIUM	
III ALL COMPOSITE STRUCTURE, HARD LAYUP	GRAPHITE REINFORCED EPOXY COMPOSITE	○ LIGHT WEIGHT ○ STIFFEST STRUCTURE ○ LOW STRESSES ○ DOES NOT REQUIRE AIR CONDITIONING	○ HIGH COST OF MATERIAL AND LABOR	○ DEVELOPMENT REQUIRED FOR APPLYING GEL COAT TO TOLERANCES REQUIRED TOI	2
IV INVESTMENT	ALUMINUM	○ LIGHT WEIGHT	○ ANNEALED STRENGTH ○ LOW MODULUS ○ REQUIRES AIR COND. POD ○ POOR SURFACE FINISH ○ COSTLY	○ HOT STATE OF ART ○ VERY HIGH MOLD DEVELOPMENT COSTS - SIZE/WEIGHT ○ (SAME AS ALUM I EXCEPT NO RESIDUAL STRESSES) ○ SURFACE POROSITY	N/A
	BRASS	○ GOOD STRENGTH ○ MODERATE STIFFNESS ○ MOST STABLE METALLIC MATERIAL	○ HEAVIER ○ REQUIRES AIR COND POD ○ COSTLY	○ (SAME AS ABOVE)	
V FILAMENT WOUND COMPOSITE BACKUP	GRAPHITE/EPOXY (PREPREG TAPE AND FILAMENT WOUND FIBER)	○ REPRODUCIBLE ○ LIGHTEST WEIGHT ○ HIGHEST STIFFNESS ○ LOW STRESS (RESIDUAL) ○ FAST, REPRODUCIBLE MACHINE CONTROLLED PROCESS	○ HIGH MATERIAL COST	○ FILAMENT WINDING FACILITY REQUIRED ○ DEVELOPMENT REQUIRED FOR RESIN FOR FACE GEL COAT APPLICATION	1

management process to provide manufacturing inputs on cost and schedule impacts.

The PRRs are conducted during the FSD phase to establish that the system is ready for efficient and economical quantity production, that adequate test planning has been accomplished, and that problems encountered have been resolved. Each PRR is conducted in accordance with DoDI 5000.38 [7] and makes the following evaluations:

a. Production Design

1. Producible at low risk

2. Design change rate stabilized at low level

3. Design validated: performance, reliability, maintainability, availability

4. Design deficiencies identified

5. Design standardized and stabilized

b. Resources

1. Plant capacity adequate

2. Skilled personnel available

3. Training programs available

c. Production Engineering and Planning

1. Production Plan developed

2. Schedule compatible with configuration item delivery requirements

3. Manufacturing methods and processes integrated with facilities, equipment, tooling, and lay-out

4. Production planning complete

5. Value engineering applied and large dollar initiatives incorporated into the TDP

6. Configuration management adequate and a baseline is established

7. Management information system adequate

d. Materials and Purchased Parts

1. Bill of materials complete

2. Make-or-buy decisions complete

3. Long lead items identified and ordered

4. Government-furnished equipment identified and its Total Quality control and disposition is agreed to by both parties.

5. Inventory control system adequate

e. Total Quality Management

1. Process control tools are in place and understood

2. Statement of work (SOW) satisfied which includes continuous improvement practices

3. Acceptance criteria exists with

emphasis on the narrowing of variability as a goal

4. Subcontractor control including flow down of TQM and its tools.

5. Management and worker involvement

6. On going training at all levels

7. Problem Prevention

8. User Involvement

f. Logistics

1. Operations support, test, and diagnostic equipment available

2. Training aids and simulators available

3. Packaging, handling, storage, and transportation (PHST) adequate

4. Spares, Foreign Military Sales (FMS) requirements, and life of type buys incorporated

g. Software

1. Plans complete

2. Rate-of-change stable

3. Configuration management adequate

4. Security adequate

h. Safety

1. Plans complete and implemented

18.6 PRODUCTION FACILITIES IDENTIFICATION

Although producibility studies and plans may define a more efficient structure for the production process, implementation of facility solutions is often constrained by defense contracting procedures. Defense contracting procedures can inhibit industry investments to modernize because profits may be reduced when costs to produce go down. Careful contract stucturing can eliminate this problem. The contractor if he's any good will do this anyway.

Factory improvements place equal emphasis on all system elements. This often leads to interesting conclusions. For example, a key feature of the DoD risk reduction program for transition from development to production (outlined in DoD 4245.7-M [1]) is the identification of a general need for productivity centers that provide training and training apparatus for updating the skills of manufacturing personnel. The systems engineering process and documentation can be used to identify facility and personnel requirements for this type of production support facility.

18.7 PRODUCTION STRATEGY/PLAN DEVELOPMENT

A production strategy is developed as part of the overall program acquisition strategy. This strategy is a comprehensive assessment of production issues that forms the foundation for a formal Production Plan. The Production Plan is prepared by contractor(s) during C/E and is presented as a completed document during FSD. DoD

4245.7-M [2], also provides useful supporting guidance for developing production planning.

Production planning review is an integral part of the overall acquisition review process. An acquisition may not proceed into production until it is determined that the principal contractors have the physical, financial, and managerial capacities to meet the cost and schedule commitments of the proposed procurement. An assessment is made of contractors' capabilities to meet surge (peacetime) and mobilization (declared national emergency) requirements, and the contractors' commitment to participate in the DoD industrial preparedness production planning program under DoDD 4005.1 [8]. Competition, value engineering, tailoring of specifications and standards, design to cost, cost benefit and trade-off assessments, preplanned product improvements, multi-year procurements, industrial modernization incentives, and other techniques are used to reduce production, operating, and support costs. Standardization, commonality, and interchangeability must be promoted throughout the acquisition cycle to reduce lead time and life cycle cost.

Production management planning and implementation also includes provisions for measuring progress toward design to cost and life cycle cost commitments.

18.8 PRODUCIBILITY ENGINEERING AND PLANNING (PEP)

The term "producibility engineering and planning" as used in DoD is identical to the term "production planning" in the academic and industrial worlds. PEP includes all those design activities and disciplines necessary to design a product that is producible, design the processes and tooling, set up the manufacturing facility, and prove the processes and facilities, before entering production.

DoD policy states that a comprehensive PEP program is requisite to entering FSD. The PEP program begins as an integral part of the design process and is conducted throughout FSD. It contains specific tasks, measurable goals, and a system for contractor accountability.

The contractor's System Engineering Management Plan (SEMP) should define how the PEP program will integrate into the overall systems engineering process. Normally, this will be an extension of the procedures used during C/E and D/V to integrate producibility "design-for" requirements into the engineering management process.

The PEP policy states that PMs are to make assessments of production risk throughout the acquisition process. These assessments are formalized by reviewing the design process through the established design review and audit mechanism, industrial resource analysis, and Production Readiness Reviews (PRRs). Normally, production risk assessment would be an integral part of the overall risk management approach. This relationship should also be detailed in the contractor's SEMP as well as PEP planning.

The PEP program extends throughout the life cycle. It includes actions required to

Figure 18-5
Production Strategy/Plan Development Outline

1. Program Production Objective
   a. Requirements
   b. Additional Program Needs

2. Production Facility Requirements
   a. Existing Industrial Base
   b. Government-Furnished Facilities
   c. Contractor Facilities/Capital Investment

3. Production Program Phasing
   a. Production/Delivery Schedule
   b. Economic Production Rate/Planned Production Rate
   c. Built-Up Rate

4. Production Risk Analysis
   a. Management
   b. Materials/Purchased Parts
   c. Facilities/Equipment
   d. Labor
   e. Design Changes
   f. Producibility

5. Producibility Engineering and Planning
   a. Design Producibility
   b. PEP
      (1) Funding Controls
      (2) Objective
      (3) Work Scope
      (4) Allocation of Human Resources
      (5) Data Items
      (6) Time/Fund Allotment

6. Contractual Consideration
   a. Statement of Work
   b. Incentives
   c. Consistency Within and Among Contracts

7. Government Support to Contractor
   a. Government-Furnished
   b. Defense Materials System/Defense Priorities System

8. Production Management Scheme
   a. Program/Matrix Staffing
   b. Plant Representative Office
   c. DoD Research and Development Laboratories
   d. Consultant Support
   e. Other Government Team Participation

maintain a capability to produce material for equipment operation and maintenance after the Production Plan is complete. The planning for these post-production activities starts in the development of the initial production strategy.

18.9 REFERENCES

1. DoDD 4245.7, "Transition from Development to Production"

2. DoD 4245.7-M, "Transition from Development to Production"

3. DoDI 5000.2, "Major System Acquisition Procedures"

4. MIL-STD-499A, "Engineering Management"

5. DoDD 4245.6, "Defense Production Management"

6. MIL-STD-1528, "Production Management"

7. DoDI 5000.38, "Production Readiness Reviews"

8. DSMC "Program Manager's Notebook"

9. DoDD 4005.1, "DoD Industrial Preparedness"

10. DSMC "DoD Manufacturing Handbook for Program Managers"

CHAPTER 19

INTEGRATED LOGISTIC SUPPORT (ILS)

19.1 INTRODUCTION

The purpose of this chapter is to address the role of integrated logistics support (ILS) within the context of the systems engineering process. The discussion centers on the key linkages between systems engineering and components of an effective ILS program. The reader is referred to reference [1] for more detailed treatment of the ILS process as it applies to the acquisition life cycle.

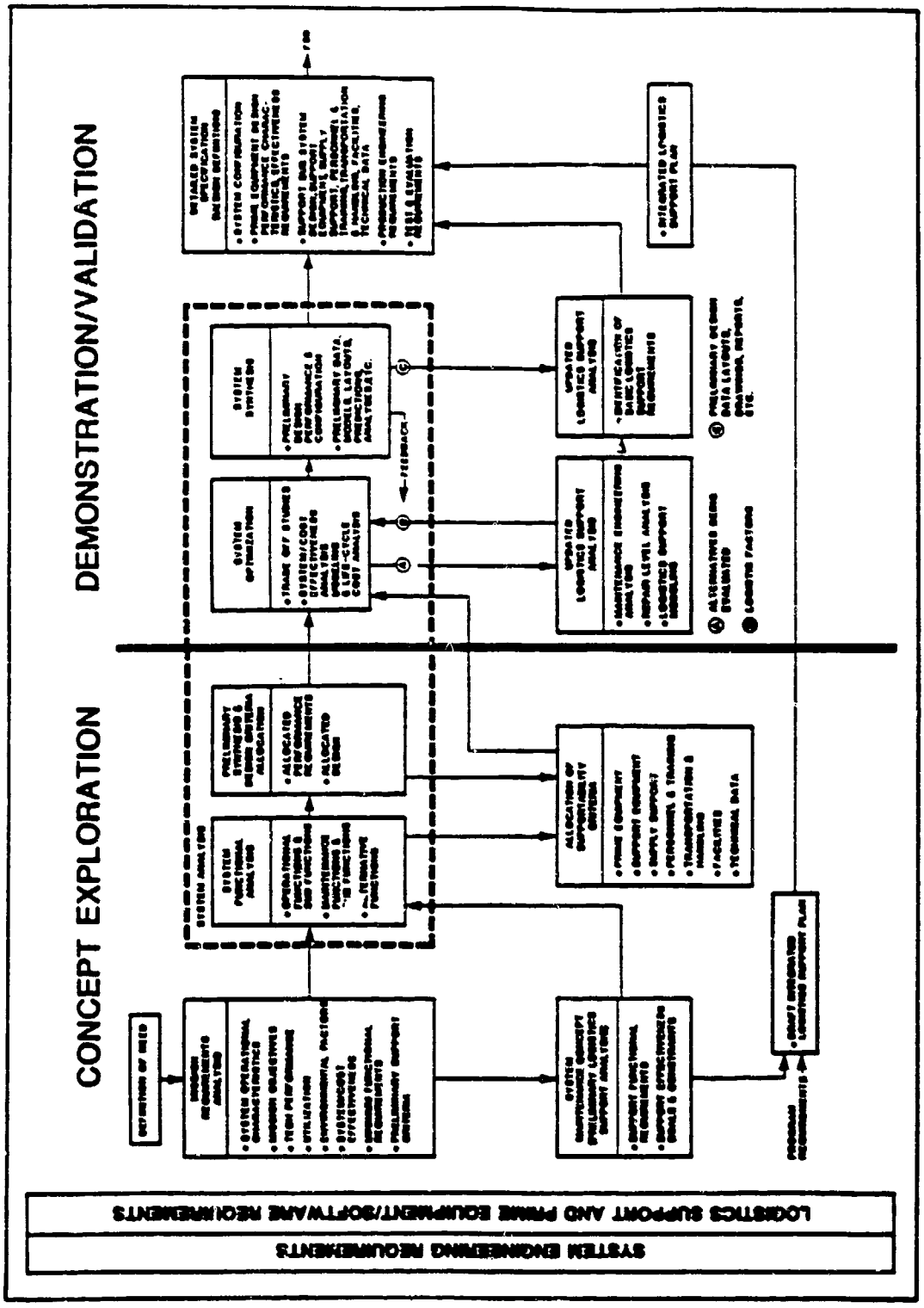
System readiness is a primary objective of the acquisition process. Department of Defense (DoD) policy requires that resources to achieve readiness receive the same emphasis as those required to achieve schedule and performance objectives (DoDD 5000.1 [2]). Such resources include those necessary to design desirable support characteristics into material systems, as well as those necessary to plan, develop, acquire, and evaluate the support.

DoDD 5000.39 [3] emphasizes early identification of supportability design requirements through integration with the mainstream engineering effort. One way to achieve this is to establish a rigorous formal relationship between the ILS process and the systems engineering process. An ILS program success hinges on how the readiness and supportability characteristics are designed into the system. These characteristics must be designed in early, during Concept Exploration/ Definition (C/E) and Concept Demonstration/ Validation (D/V), and continuously re-evaluated through Full Scale Development (FSD). They must be considered in performing functional and trade-off analyses. The systems engineering process provides a framework for enabling the effective acquisition of a supportable system.

Figure 19-1 illustrates the analytic and decision making process involved in the application of systems engineering to acquisition management. The example shown is for the C/E and D/V phases. Within the framework of this process, government operational needs are analyzed; the various design concepts are synthesized, evaluated, and optimized in trade studies; and the "best" design is selected.

The upper portion of Figure 19-1 portrays those systems engineering efforts and activities that define the requirements for prime item equipment and associated software. The lower portion of Figure 19-1 contains efforts and activities that define the related logistic support requirements. Attainable supportability characteristics are defined throughout the design process using design trade-off efforts involving all product design and support disciplines, including reliability and maintainability (R&M). The contractor must give equal emphasis during requirements identification and allocation to analysis of support functions using tools such

Figure 19-1
ILS and the Systems Engineering Process

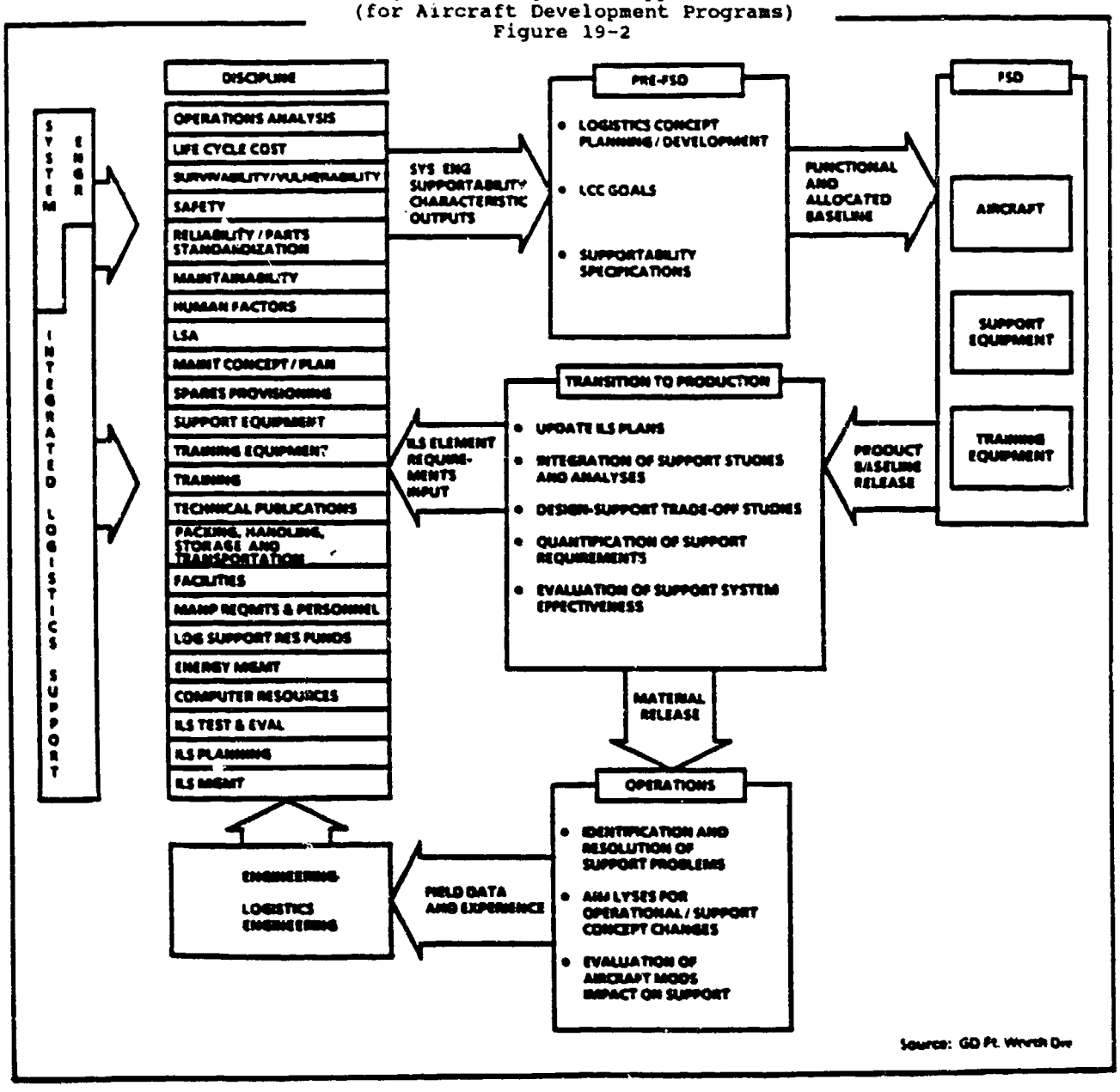


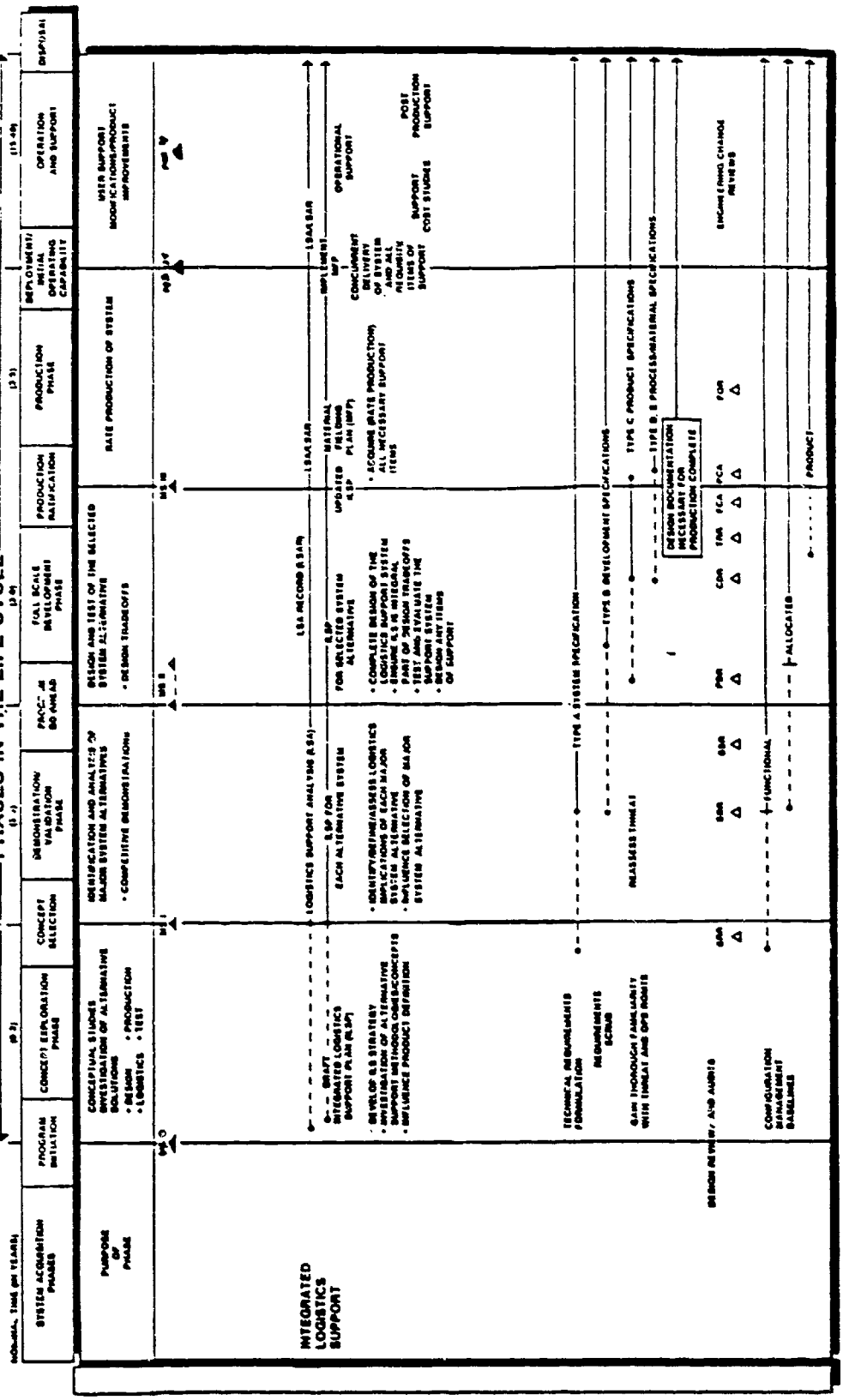
as the functional flow block diagram (FFBD) and requirements allocation sheet (RAS).

To achieve the necessary balance of ILS factors within the systems engineering process, the contractor must define trade- off and decision criteria that adequately address support requirements. A balanced integration of logistic support requirements into the systems engineering process will achieve the following objectives:

a. Accomplish readiness objectives that will be challenging but attainable

Typical Contractor Systems Engineering Linkages with Logistic Support Elements (for Aircraft Development Programs)
Figure 19-2




PHASES IN THE LIFE CYCLE
SYSTEM ACQUISITION PHASES
PURPOSE OF PHASE
PROGRAM INITIATION
CONCEPT EXPLORATION PHASE
CONCEPT SELECTION
DEMONSTRATION/ VALIDATION PHASE
PROCEED AHEAD
FULL SCALE DEVELOPMENT PHASE
PRODUCTION RATIFICATION
PRODUCTION PHASE
DEPLOYMENT/ INITIAL OPERATING CAPABILITY
OPERATION AND SUPPORT
DISPOSAL
INTEGRATED LOGISTICS SUPPORT
LSA RECORD (LSAR)
LSAR
LSAR
OPERATIONAL SUPPORT
POST PRODUCTION SUPPORT
TYPE A SYSTEM SPECIFICATION
TYPE B DEVELOPMENT SPECIFICATIONS
TYPE C PRODUCT SPECIFICATIONS
TYPE B, B PROCESS/MATERIAL SPECIFICATIONS
DESIGN DOCUMENTATION NECESSARY FOR PRODUCTION COMPLETE
FUNCTIONAL
ALLOCATED
PRODUCT

b. Accomplish realistic R&M requirements to achieve these objectives

c. Identify support and manpower drivers

d. Assign appropriate priority to ILS element requirements in system design trade-offs.

19.2 ILS-SYSTEMS ENGINEERING MANAGEMENT INTERACTION

Figure 19-2 illustrates typical areas of management interaction between systems engineering and ILS program elements for an aircraft development program.

This figure shows a broad array of logistics related functional disciplines in organizational cells on the left side of the linkage diagram and illustrates the complexity of integrating support into the design process of large programs. These linkages must be formally addressed in the contractor's System Engineering Management Plan (SEMP) and Integrated Logistic Support Plan (ILSP). The ILS role in relation to these interactions is discussed below.

Systems engineering supportability characteristic outputs are developed by discipline specialists participating in the systems engineering process prior to FSD. Functional and allocated baselines are developed during C/E and D/V, respectively. The successful integration of ILS into system design is partially demonstrated by the extent of effective supportability characteristics and requirements in system specifications (Type A) and development specifications (Type B). Figure 19-3 displays the phasing of the functional, allocated, and product baselines and their related specifications with respect to other system acquisition management milestones. The dotted lines in Figure 19-3 portray the period of documentation review, while the solid lines portray continued use under government configuration management. The format of the system specification (type A) has provisions for identification of supportability characteristics (R&M) and logistics concept requirements (e.g., maintenance, supply, and facilities). The development specifications (type B) contains requirements for major configuration items (CIs), components, and software. These specifications (Types A and B) control the engineering design activities (refer to the upper right portion of Figure 19-2) during FSD.

The product baseline release in Figure 19-2 provides detailed design documentation for the transition to production. Timely release of the major configuration items and their support and training equipment designs is required for scheduling logistic activities such as preparation of final technical manuals, preparation and processing of provisioning documentation, and development of packaging requirements.

Material release refers to the decision to proceed with deployment of the first system in its military role. This event signifies that all support has been acquired and can be provided concurrently, or prior to this initial deployment.

Field data and experience provide the means of assessing supportability and attained readiness, instituting required improvements, and updating the ILS elements.

19.3 COMPUTER-AIDED ACQUISITION AND LOGISTIC SUPPORT (CALS)

Widespread industry use of computer aided design and engineering (CAD/CAE) has created a new environment where product description data is becoming available in digital form to support a wide range of DoD and industry applications. CALS is a DoD and industry program to enable and accelerate the use and integration of this digital technical information during weapon system acquisition, design, development, manufacture and support.

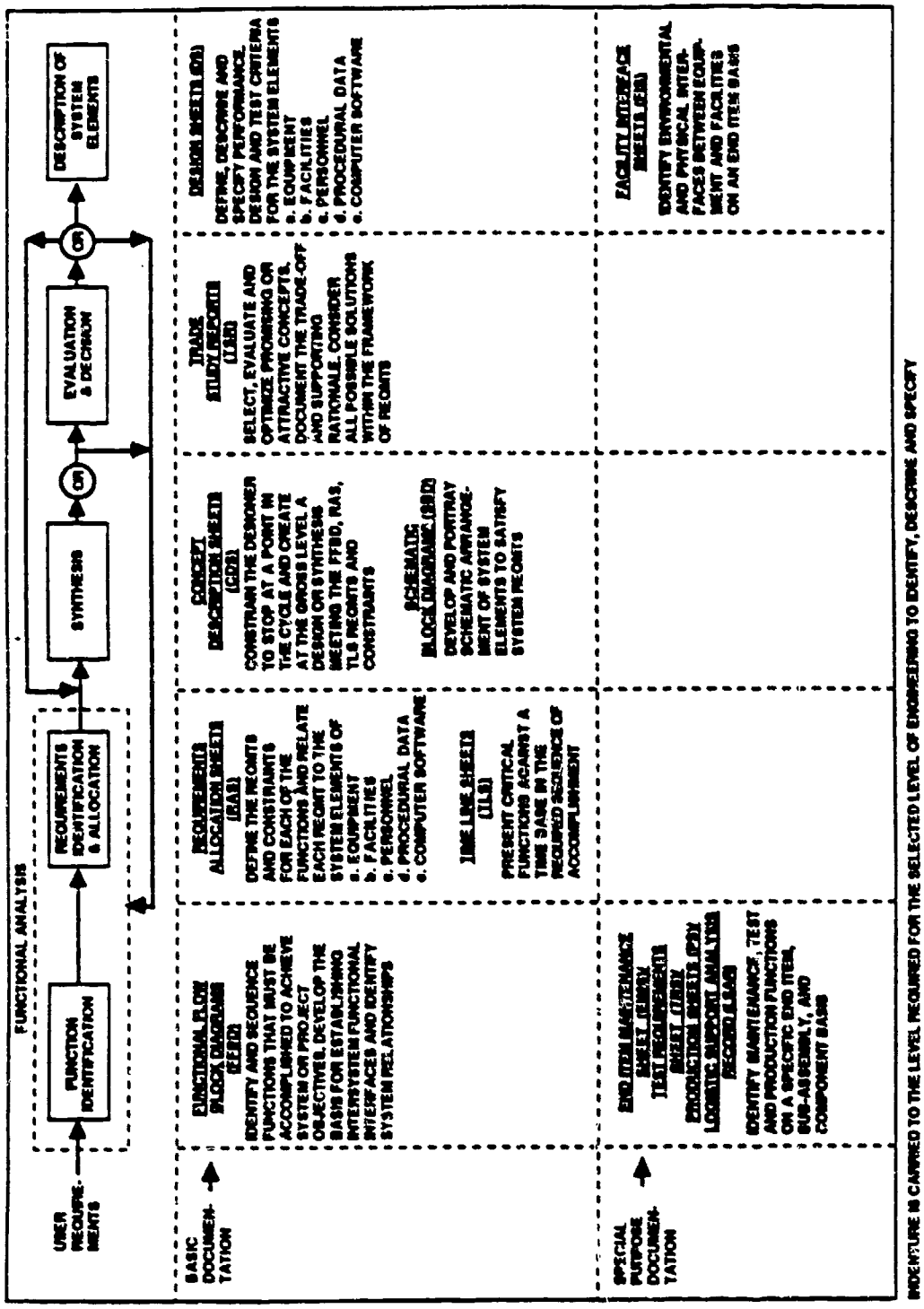
CALS will transition from current paper intensive mode to a highly automated and integrated mode of operation , thereby substantially improving productivity and quality. The Deputy Secretary of Defense launched the DoD CALS program in 1985, with the goal that by 1990 new weapon systems would acquire technical data in digital form, or obtain government access to contractor integrated data bases in lieu of paper deliverables. The potential exists for substantial quality improvements and reductions in acquisition and support costs through CALS.

To achieve these benefits, a phased CALS strategy has been planned by a team consisting of the Office of the Secretary of Defense (OSD), the Services, and industry. Phase I will replace paper documentation transfers with digital file exchanges and begin process integration. This will be implemented between now and the early 1990's. In parallel, technology is being developed for Phase II which involves substantial integration of current processes to take advantage of a shared data base environment in the early 1990s and beyond. The main roles od DoD in both phase are 1) to accelerate the development and test of interchange and data access standards, 2) to fund demonstrations and technology development in high risk areas, 3) to encourage industry investment in integrated processes by establishing contract requirements and incentives, and 4) to implement CALS capabilities in DoD's own extensive automated systems.

The CALS program has made significant progress. Technical information exchange standards have been publihed, a standards application testing program has begun, and the incorporation of CALS concepts into DoD and industrial infrastructures is underway. Advance technology reswarch and development to meet long term CALS requirements is being accelerated through close DoD and industry collaboration.

CALS planning efforts are concentrating on the orderly insertion of technological advances in digital technical data management and use into the existing defense acquisition and logistic support processes. CALS provides a unique opportunity to achieve major productivity and quality improvements through carefully planned and managed investment by both DoD and industry. Initially, the changes will be gradual, as building blocks are put into place and specific portions of the weapon system life cycle are enhanced. Benefits will begin to accrue as productivity improves in both DoD and industry. CALS implementation will result in lower weapon system life cycle costs, shortened acquisition times, and improvements in reliability and maintainability. Most importantly, the ability of the Defense components to perform their

Figure 19-4
Basic and Special Purpose Systems
Engineering Documentation



assigned missions will continue during this technology insertion process.

19.4 SYSTEMS ENGINEERING AND LOGISTIC SUPPORT ANALYSIS

It is the resposibility of the government Program Manager (PM) to coordinate the communication and planning of work between the design engineers and the logistics managers. The ILS Manager's LSA Plan should identify the scope of analytical effort for each acquisition phase, and must be coordinated with the contractor's SEMP. Together these documents define the detailed relationship of both the analysis and data developed under MIL-STD-1388-1A [4] and MIL-STD-499A [5]. A general area of concern is the non-duplication of analysis and data, and the requirement for traceability between systems engineering and LSA data elements. It should be noted that analysis of logistic support functions has always been an integral part of the systems engineering process described by military specifications and standards. MIL-STD-1388-1A [4] provides a contemporary focus on specific requirements.

Figure 19-4 illustrates the basic documentation used in the systems engineering process. It can be seen that many of these documentation items define and describe logistic elements. The LSA Record (LSAR) provides an expansion of the maintenance analysis defined on the End Item Maintenance Sheet (EIMS). Figure 19-5 shows the relationship between systems engineering documentation and the LSA tasks identified in MIL-STD-1388-1A [4].The right-hand section of the matrix illustrates the principal interface with the systems engineering documentation described in Figure 19-4 and MIL-STD-499A [5]. Each interfacing area should be described in detail in the contractor LSA and SEMP planning to avoid duplication of effort and provide traceability and correlation of system requirements.

MIL-STD-1388-2A [6] is presently undergoing revision as MIL-STD-1388-2B. Under this revision, the LSA Records (A-H and J) will be deleted and the LSA Master tables will be replaced by relational tables formats. The number of reports will be reduced from 80 to 21. These remaining 21 reports are product-oriented reports and not analysis reports. The accompanying Joint Services LSAR automated data processing (ADP) system is being developed as a relational data base platform which will provide the following advantages: 1) the LSAR ADP system will be easier to change/update,. 2) the "hooks" for using interactive systems engineering tools (e.g., level of repair modeling) will be available, 3) one time storage of data elements will improve the consistency and quality of products, 4)ad hoc report capability, and 5) online access and review of LSAR data. Front end data entry screens and report generation capabilities will also be available as part of the LSAR software. This software package will be exportable to industry and government users.

19.5 IMPACT OF R&M ON ILS

R&M parameters are the most effective logistics engineering tools for influencing and interacting with the systems engineering process. Establishment of effective R&M requirements for the total system and the allocation of tose requirements to lower level components are a vital influence on mission

Figure 19-5(1 of 2)
LSA/Systems Engineering Documentation Interface

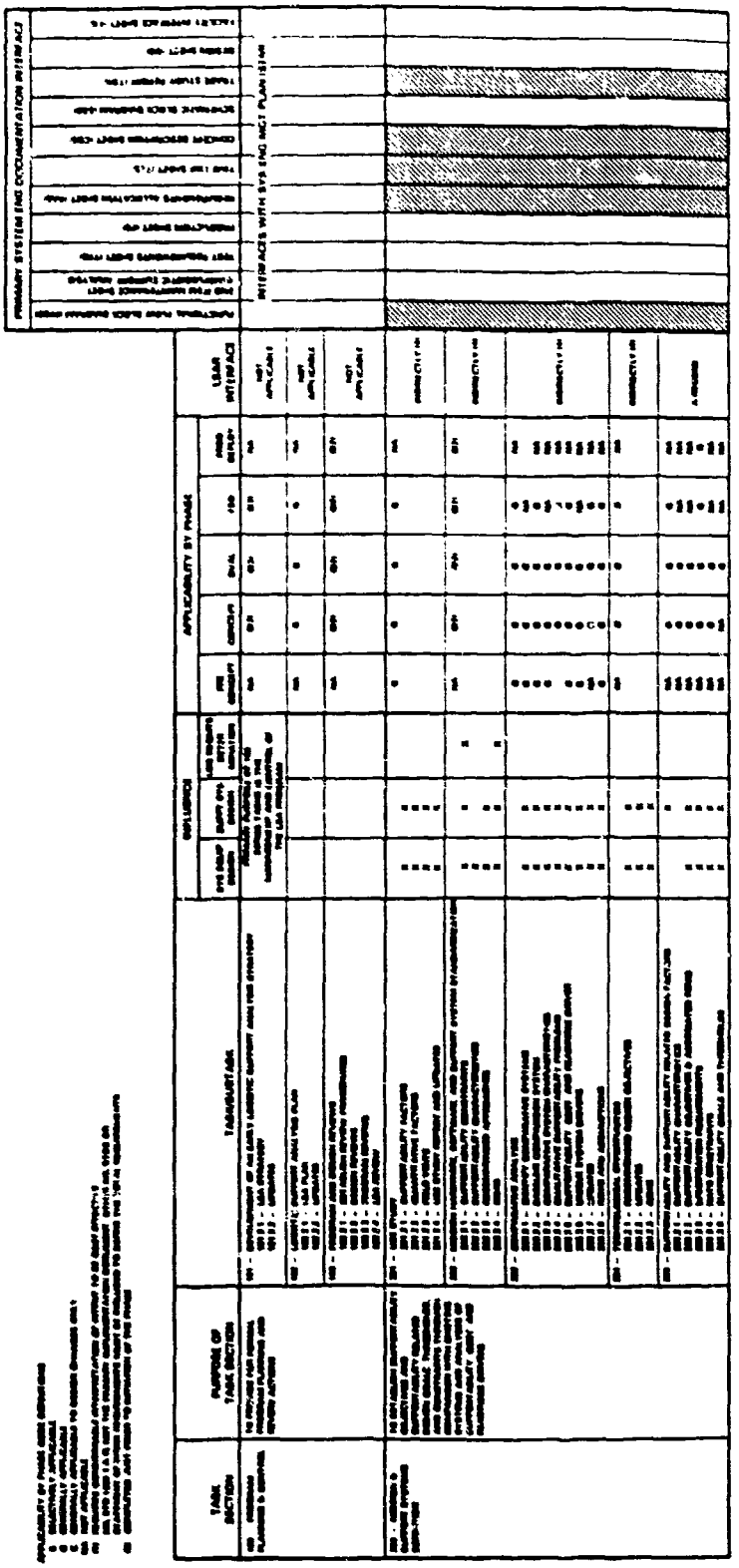
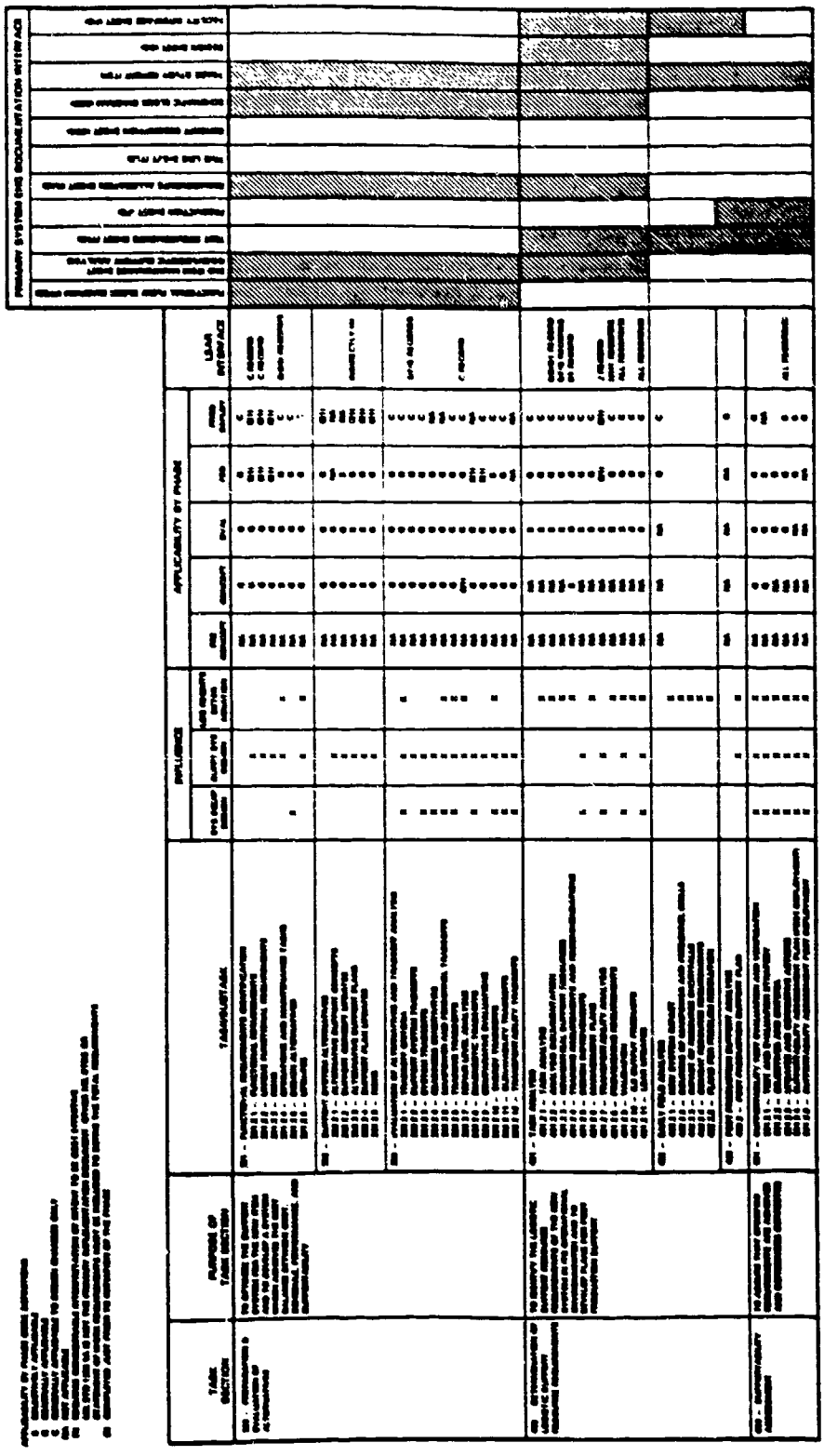


Figure 19-5(2)
LSA/Systems Engineering Documentation Interface



success and operation and support (O&S) cost. R&M parameters listed in DoDD 5000.40 [7] and summarized in Figure 19-6, include the following: mission success, readiness, maintenance manpower requirements and costs, and logistic support cost.

Mission success is greatly influenced by mission reliability (mean time between critical failures that impact the mission) and mission maintainability (mean time to restore functions during the mission). Readiness is partially determined by mean time between downing events and mean time to restore the system. Maintenance manpower requirements and costs are affected by the time between the manhours to perform maintenance actions. Logistic support costs related to parts are determined by the mean time between removal of repairables and consumables, and the total of all costs to

System R&M Parameters
Figure 19-6

OBJECTIVE	R PARAMETER	M PARAMETER
Mission Success	Mission Time Between Critical Failures	Mission Time to Restore Functions
Readiness	Mean Time Between Downing Events	Mean Time To Restore Systems
Maintenance Manpower and Costs	Mean Time Between Maintenance Actions	Direct Manhours per Maintenance Action
Logistics Support Cost	Mean Time Between Removals	Total Parts Cost Per Removal

remove, replace, transport, and repair components at all levels of maintenance.

The ILS program must ensure that the R&M parameters are consistent with planned peacetime and wartime operational environments/scenarios, and the support that will be provided under these conditions. Failure to fully account for the effects of item design, quality, operation, maintenance, and repair can lead to a substantial shortfall in operational performance and an overrun of logistic support costs.

R&M considerations, as other ILS considerations, are incorporated into system design through the systems engineering process. In particular, the synthesis and trade-off analysis methodologies described in Chapters 7 and 8 of this guide ensure that ILS parameters are incorporated along with other technical and program requirements to produce a balanced design.

19.6 SUPPORT SYSTEM DESIGN AND SYSTEMS ENGINEERING

The support system design functions usually include the design of automatic and non-automatic test and support equipment, simulators, training equipment, mobile maintenance trainers, analysis of maintenance and repair facility requirements, and packaging and transportation studies. Using LSA and systems engineering techniques, the ILS program should: 1) Integrate system performance and support requirements and incorporate support parameters in system specifications, 2) Identify ILS discipline design requirements for configuration items early and refine them throughout the life cycle, 3) Analyze government-furnished equipment (GFE) support system items and integrate these items into the total system design, 4) Emphasize ILS requirements relative to hardware, firmware, and software interface design considerations, and 5) Include procedures for determining the effect of support system design items in the configuration management program to provide total system consideration of proposed changes.

19.7 COMPUTER SOFTWARE SUPPORTABILITY

Software design and support considerations are important to the success of the ILS program. ILS planning should incorporate requirements of DoD-STD-2167A [8] for ensuring the supportability of all computer software. This will provide a software management system that parallels the hardware requirement system. DoD-STD-2167A [8] requirements for software are explained in detail in Chapter 20 of this guide. In conjunction with the approved SEMP under MIL-STD-499A [5], DoD-STD-2167A [8] provides a controlled and structured software development process involving software design specifications, design reviews, milestones, documentation, configuration control and identification, validation, and verification.

In addition, ILS planning should assure that either the ILSP or the Computer Resources Life Cycle Management Plan (CRLCMP) adequately address support planning for user programmable firmware and software. This planning should highlight documentation, training, support equipment, and facility requirements for software and be consistent with systems engineering, software,

Due to the increasingly important role of software, special attention should be given to identifying and evaluating software maintenance requirements during systems analysis and planning for adequate hardware and services support during the operation phase of the program.

19.8 SUMMARY

The systems engineering process produces a balanced design that will reflect the impact of various R&M options and other specialty engineering analyses dealing with readiness objectives and O&S costs. Unrealistic R&M requirements can be avoided by analyzing the achievements of prior systems and estimating the impact of the technological enhancements incorporated in the new system. Integration of the LSA process with the systems engineering and design processes should promote the achievement of program supportability objectives.

19.9 REFERENCES

1. DSMC "Integrated Logistic Support Guide"

2. DoDD 5000.1, "Major System Acquisitions"

3. DoDD 5000.39, "Acquisition and Management of Integrated Logistic Support for Systems and Equipment"

4. MIL-STD-1388-1A, "Logistic Support Analysis"

5. MIL-STD-499A, "Engineering Management"

6. MIL-STD-1388-2A, "Logistic Support Analysis Record"

7. DoDD 5000.40, "Reliability and Maintainability"

8. DoD-STD-2167A, "Defense System Software Development"

CHAPTER 20

SOFTWARE DEVELOPMENT PROCESS

20.1 INTRODUCTION

The development of a weapon system requires integrating technical, administrative, and management disciplines into a cohesive, well-planned, and rigorously controlled process. As a critical component of a weapon system, software must be developed under a similarly disciplined engineering process. In his book "Software Engineering Concepts" [1], Richard Fairley defines software engineering as "***the technological and managerial discipline concerned with systematic production and maintenance of software products that are developed and modified on time and within cost estimates***".

Barry Boehm [2] defines software engineering as a discipline that "***involves the practical application of scientific knowledge to the design and construction of computer programs and the associated documentation required to develop, operate, and maintain them***".

The main point is that the software development process must be scientific and disciplined. This is not different from the hardware development process. As with hardware, the goal of the software development process is to consistently produce a quality product, within schedule and cost.

With the publication of DOD-STD-2167A [3], the DoD took the first step toward a standardized, systems engineering approach to software development. This standard is supported by other military documents and describes a standard process and documentation for computer software development. To use this standard effectively, the systems engineer must have a thorough understanding of the system being developed; particularly the overall system requirements and constraints. Requirements must be defined early through trade studies and prototyping. Traceability of requirements must be maintained throughout the acquisition life cycle and any requirement that cannot be traced up to a higher requirement should be modified or eliminated.

The material presented in this chapter was extracted from the DSMC "Mission Critical Computer Resources Management Guide" [4] and modified accordingly. It will describe activities that occur in a "typical" program. The reader should understand that real programs seldom actually follow this "typical" profile. Phases can occur concurrently, they can be bypassed altogether, protracted, or condensed to satisfy the needs of the overall program objectives. The point to understand is that although the process is somewhat constant,

its chronological occurrence is not fixed. The following sections describes the classical approach to software development.

20.2 SUMMARY OF DEVELOPMENT ACTIVITIES

Figure 20-1 presents an overview of the development activities of an integrated software and hardware system as reflected in DOD-STD-2167A [3].

All weapon system development programs begin with a determination of system level requirements. These activities occur during the Concept Exploration/ Definition (C/E) and the Concept Demonstration/ Validation (D/V) phases of the acquisition cycle.

The Systems Requirements Review (SRR) may be held after the initial determination of system functions (functional analysis) and the preliminary allocation of these functions to configuration items. The SRR provides an opportunity for an initial insight into the developer's direction, progress and convergence on a system configuration.

The System Design Review (SDR) is a review of the overall system requirements in order to establish the system functional baseline documented by the system specification. The functional baseline should allocate requirements to both hardware and software configuration items.

The development of both hardware

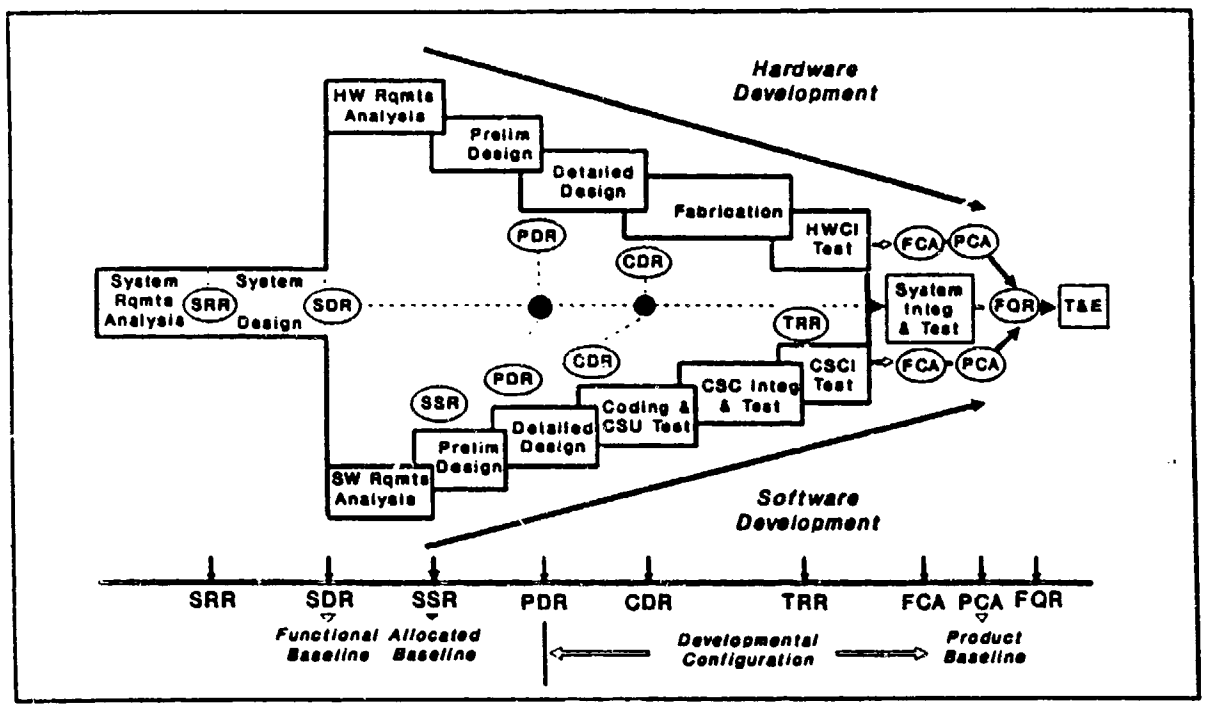


Figure 20-1 Software/ Hardware Development

and software can begin once the functional baseline is established. These activities occur in the Full Scale Development (FSD) phase and are monitored through informal and formal reviews and audits as described in MIL-STD-1521B [5]. The allocated baseline for software should be established at the Software Specification Review (SSR). For hardware the allocated baseline is normally established at the Preliminary Design Review (PDR); but no later than the Critical Design Review (CDR).

Building of the developmental products can start once the design effort is completed. For hardware this building effort is called fabrication and for software it is called coding and testing. Testing is further subdivided into Computer Software Unit (CSU) testing and Computer Software Component (CSC) integration and testing. After the items are built, formalized testing should take place in accordance with approved test plans and procedures. A Test Readiness Review (TRR) will be conducted by the government in order to determine the developer's readiness to perform formalized acceptance testing. Completion of software testing will lead to system integration and testing. Both Functional Configuration Audits (FCA) and Physical Configuration Audits (PCA) will be conducted on both hardware and software configuration items in order to establish the respective product baselines. After a Formal Qualification Review (FQR) at the system level, the integrated system will be turned over to the government for operational testing as defined in the system's Test and Evaluation Master Plan (TEMP). Successful completion of this testing indicates that the product is fully defined and ready to be manufactured. For hardware, the production line would begin to assemble carbon copy items. For software, turning out copies is a trivial process since the product is complete and needs only to be duplicated on the required media for transfer to the target system computer.

20.3 SYSTEM REQUIREMENTS ANALYSIS/DESIGN

Figure 20-2 depicts the activities and products associated with the C/E and D/V phases. The C/E and D/V phase activities are system oriented to:

a. Define overall project objectives

b. Determine project feasibility

c. Develop acquisition/development strategy

d. Establish resource cost and schedule

e. Define hardware/software interrelationships

f. Define technical and business functions and performance.

The first step in any system development is to generate the system level requirements and reflect them in a System/ Segment Specification (SSS) (Type A Specification). It doesn't make any difference whether it is a hardware only, a software only, or a hardware and software system; the most important and critical aspect of weapon system development is to "nail down" the system requirements. These requirements must first be finalized at the functional level,

before being allocated to hardware and software.

The requirements are nailed down through a series of engineering studies and trade-offs. These studies include:

a. **Requirements Refinement** - The overall system requirements, including constraints, should be examined to identify the factors that drive requirements for computer resources. These factors may include system interfaces, interoperability, communication functions, personnel functions, the anticipated level and urgency of change, and requirements for reliability and responsive support.

b. **Operational Concept Analysis** - The operational concept should be analyzed in order to determine the role of computer resources. Particular attention is paid to requirements for mission preparation, operator interface, control functions, and mission analysis.

c. **Trade-off and Optimization** - The effects of system constraints such as the operations concept, the support concept, performance requirements, logistics, availability and maturity of technology, and limitations on cost, schedule, and resources are determined. Alternative computer resources approaches are studied to:

1) meet operational, interoperability, and support requirements

2) determine how the system requirements of reliability and maintainability

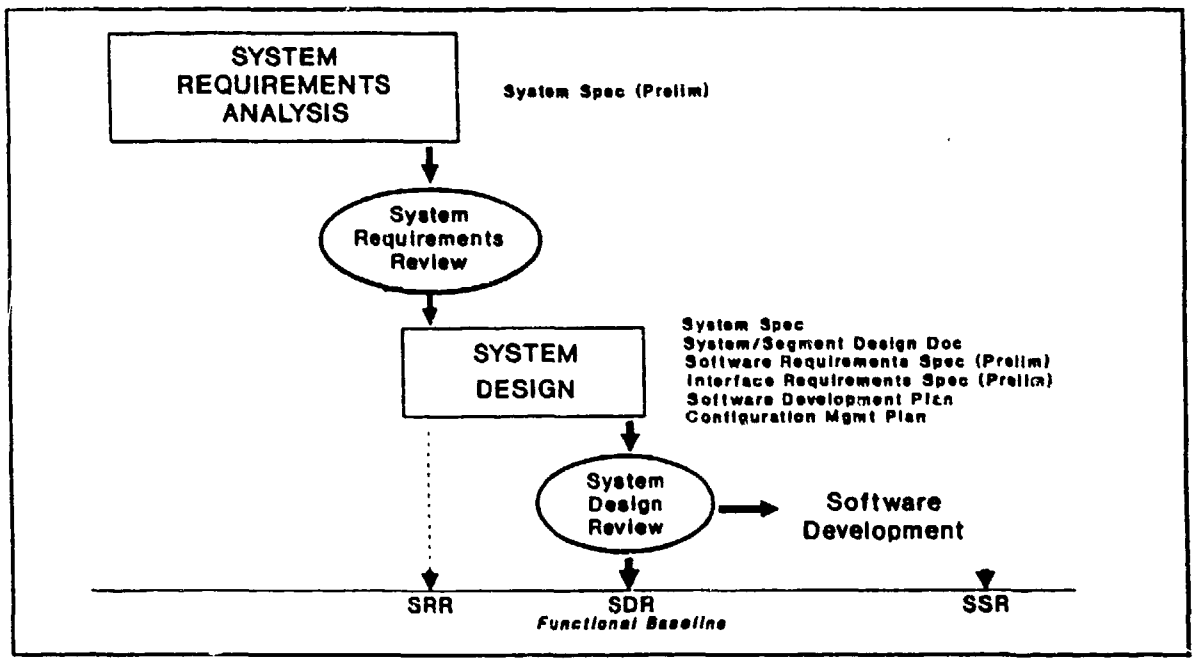


Figure 20-2 System Requirements Analysis

(R & M) will be satisfied

3) determine how requirements for system security will be met.

A determination will also be made regarding the suitability of standard computer languages and instruction set architectures.

d. **Risk** - For each approach, the risks associated with computer resources are evaluated. Typical risk areas include compiler maturity, availability and maturity of the software support tools, loosely defined or incomplete interface definitions, and lack of adequate computer memory or throughput capability.

20.3.1 System Design

System design begins on or about the time of the SRR. The major function of system design is to establish the functional baseline of the system by updating and approving the system specification and the operational concept; by developing the initial subsystem/segment designs; and by further refining the systems engineering planning activities to be employed during system's development. Typical products are:

a. System Specification

b. System/Segment Designs

c. Configura Management Plan (CMP)

d. Computer Resources Life Cycle Management Plan (CRLCMP)

e. Preliminary Software Requirements Specification (SRS);

f. Preliminary Interface Requirements Specification (IRS);

20.4 SOFTWARE DEVELOPMENT

Before undertaking a discussion of software development it will be necessary to present the following definitions:

a. **Computer Software Configuration Item (CSCI)** - A configuration item for computer software.

b. **Computer Software Component (CSC)** - A distinct part of a computer software configuration item (CSCI). CSCs may be further decomposed into other CSCs and Computer Software Units.

c. **Computer Software Unit** - An element specified in the design of a Computer Software Component (CSC) that is separately testable. A CSU is the lowest level of software decomposition.

Weapon system software is partitioned into CSCIs based on the program office's management strategy. Each CSCI is managed individually and follows its own development cycle. The software development cycle is defined in DOD-STD-2167A [3] and consists of eight major activities: 1) Systems Requirements Analysis/Design, 2) Software Requirements Analysis, 3) Preliminary Design, 4) Detailed Design, 5) Coding and CSU Testing, 6) CSC Integration and Testing, 7) CSCI Testing,and 8) Systems Integration and Testing.

These steps typically occur during FSD, although they may occur one or more times during each of the system life cycle phases [6]. This is especially true if software prototyping is performed during the D/V Phase. The steps are not simply linear since software development is iterative in nature and any step may be repeated many times during the course of system development. For example, problems discovered during software integration and testing may force the software designers to go back and redo the Software Requirements Analysis and all the subsequent steps.

Managing software is very similar to managing hardware; both require discipline and control in order to succeed. An important part of the control process is the formal determination of whether or not the developer is ready to proceed to the next step. This is usually determined through a series of design reviews and audits. Software reviews and audits can occur in conjunction with hardware reviews; but they do not necessarily have to. It is important that appropriate system level reviews be held at strategic intervals. This will focus everyone's (hardware and software personnel) attention on system design and leads to timely baselines for the hardware, the software, and all the interfaces. Software development has two major reviews that are separate from hardware reviews: the Software Specification Review (SSR) and the Test Readiness Review (TRR).

The SSR is a formal review of a CSCI's requirements as specified in the software specifications . A collective SSR for a group of configuration items (CIs), addressing each configuration item individually, may be held when such an approach is advantageous to the government. Its purpose is to establish the allocated baseline for preliminary CSCI design by demonstrating to the government the adequacy of the software specifications.

The TRR is a formal review of the contractor's readiness to begin formal CSCI testing. It is conducted after software test procedures are available and CSC integration testing is complete. The purpose of the TRR is to determine whether the contractor is ready to begin formal CSCI testing that can be witnessed by the government. A technical understanding must be reached on the informal test results, and on the validity and the degree of completeness of such documents as an operator's manual, a user's manual, and a computer programmer's manual.

20.4.1 Software Requirements Analysis

The first step in the software development cycle is the Software Requirements Analysis (Figure 20-3). The purpose of the Software Requirements Analysis is to establish detailed functional, performance, interface, and qualification requirements for each CSCI based on the System Specification. The means of testing and examining the software are also identified. During requirements analysis, prototype versions of high risk areas, user interfaces, and/or systems skeletons may be partially designed and coded. Prototyping is an excellent tool for performing requirements analysis.

The developer should also identify

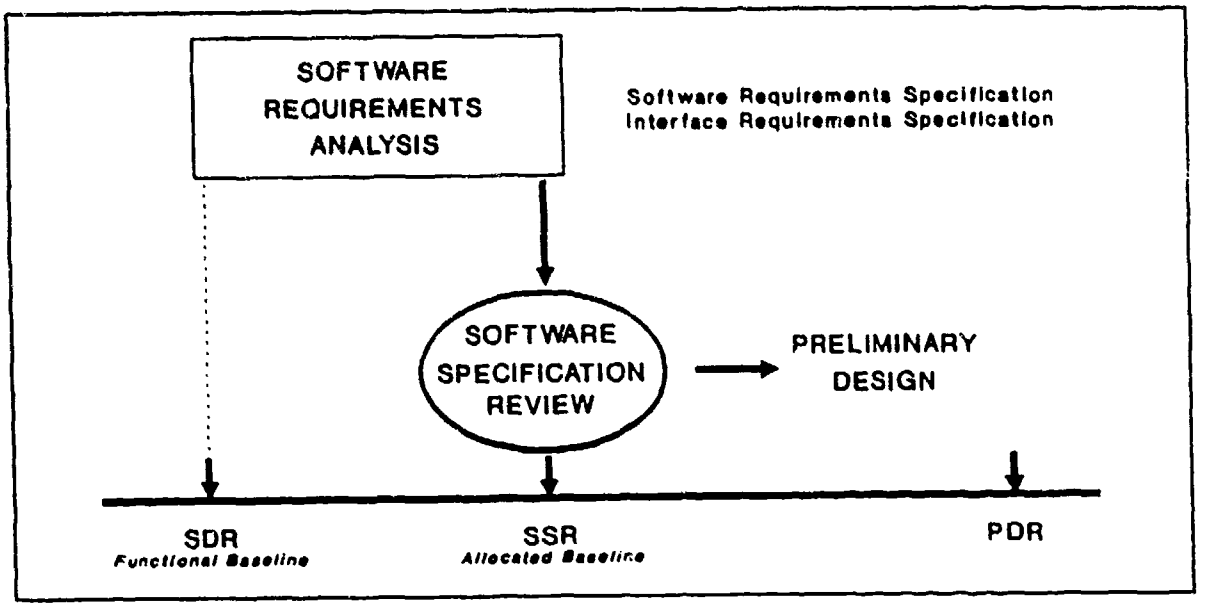


Figure 20-3 Software Requirements Analysis

support tools and resources, and establish timing and sizing estimates. The Program Manager must ensure that all software requirements, as reflected in the software development specifications, are traceable to the system specification and that the Software Development Plan (SDP) is updated to identify the required resources, facilities, personnel, development schedule and milestones, and software tools. The developer may also customize the techniques, methodologies, standards and procedures to be used in software development.

The outputs of the Software Requirements Analysis are final versions of the software specifications, and an updated SDP. These documents will be reviewed at the SSR. The Computer Resources Life Cycle Management Plan (CRLCMP) may also be updated.

20.4.2 Preliminary Design

After the software allocated baseline is established, the developer proceeds into the Software Preliminary Design (Figure 20-4). Preliminary design activity determines the overall structure of the software to be built. Based on the requirements, the developer partitions the software into components and defines the function of each component and the relationships between them. Input and output relationships with external devices (such as displays and sensors) are refined according to the hardware configuration and software structure. The timing and memory budget for components are established to ensure that the software requirements can be satisfied within the hardware constraints.

The developer should provide a preliminary design that insures clear traceability of requirements from software

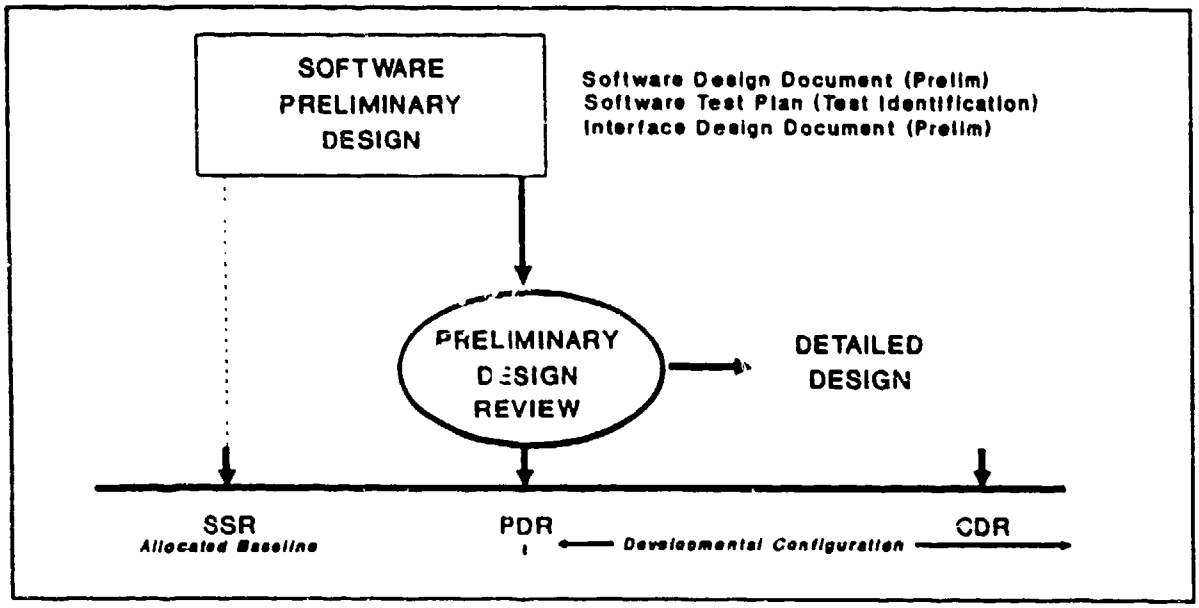


Figure 20-4 Software Preliminary Design

specifications down to the software components for each CSCI. The software design is reflected in the preliminary Software Design Document (SDD) and Interface Design Document (IDD). These documents will describe the system architecture, memory and processing time allocations, interrupt requirements, timing and sequencing considerations, and input/output constraints for each software component. The developer should also generate a Software Test Plan (STP) outlining the proposed test program and establishing test requirements for software integration and testing.

The output of the contractor's efforts are preliminary versions of the software design documents and the STP. These documents are reviewed during the Throughout the development effort, the developer will conduct informal design reviews, inspections, and walkthroughs to evaluate the progress and correctness of the design for each software component. The results of these inspections will serve as the basis for material presented at the PDR.

20.4.3 Detailed Design

The purpose of the Detailed Design (Figure 20-5) activity is to logically define and complete the detailed software design (not coding) that satisfies the allocated requirements. The level of detail of this design must be such that the programming of the computer program can be accomplished by someone other than the original designer. The component's function, its inputs and outputs, plus any constraints (such as memory size or response time) should be defined. Logical, static, dynamic

relationships among the components should be specified and the component and system integration test procedures generated.

A complete detailed design includes not only a description of the computer processes to be performed but also detailed descriptions of the data to be processed. A data dictionary is an effective way of documenting this needed design information. For software that processes or manipulates a large amount of interrelated data, the structure of the data itself should be defined.

Components coded in assembly language or other "non-standard" languages should be clearly defined and the reasons for the departure justified. Any special conditions that must be followed when programming should be similarly described and clearly documented [6]. These exceptions are normally addressed in the SDP.

During the entire design and development process the contractor should document the development of each unit, component, and CSCI in software development folders (SDFs). A separate SDF should be maintained for each unit, each component, and each CSCI. The SDFs are normally maintained for the duration of the contract and made available for government review upon request. A set of SDFs may include the following type of information:

a. Design considerations and constraints

b. Design documentation and data

c. Schedule and status information

d. Test requirements and responsibilities

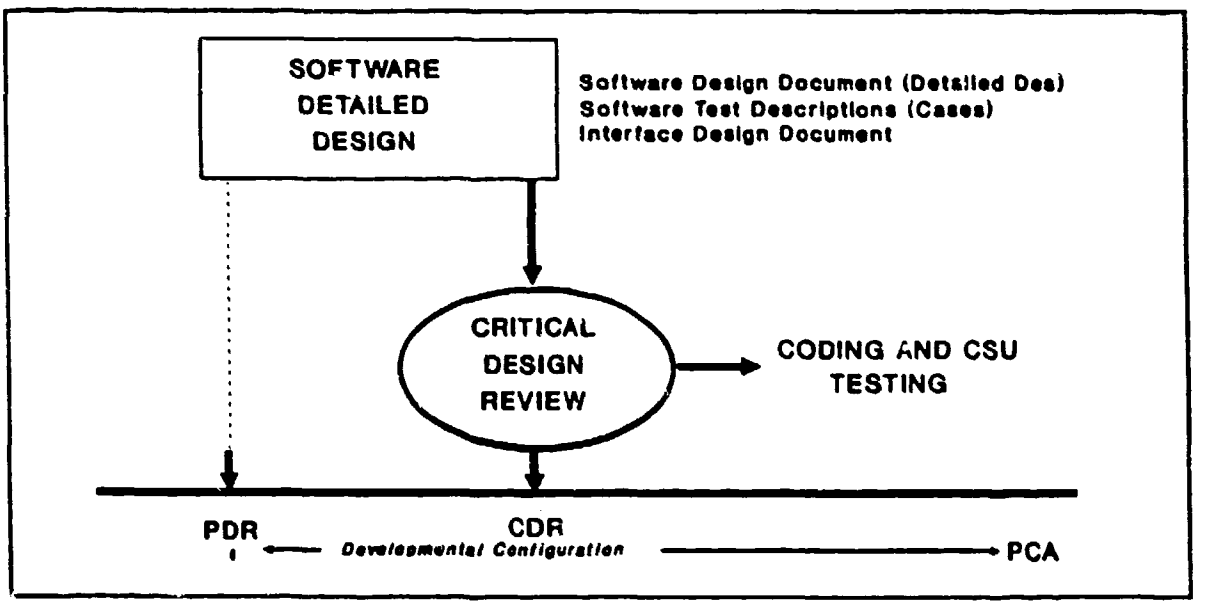


Figure 20-5 Software Detailed Design

e. Test cases, procedures and results.

The contractor documents and implements procedures for establishing and maintaining SDFs in a Software Development Library. The library is a management tool used by the contractor to assist in developmental configuration management. It serves as a "storage house" to control access of software, documentation, and associated tools and procedures used to facilitate the orderly development and subsequent support of software [8].

A CDR is conducted at the conclusion of the detailed design. The CDR should assure that the software design satisfies the requirements of both the system level specification and the software development specifications. Following an acceptable CDR, and not before, the design should be released for coding and unit testing. This process may occur incrementally with individual releases of CSCIs.

20.4.4 Coding and CSU Testing

The purpose of programming is to translate the detailed software design into a programming language such as Ada. It is during the programming activity that listings of the source program are generated (Figure 20-6). Based on the detailed software design presented in the design specification, programming of each unit is accomplished by the assigned programmer in the specified programming language, usually Ada. As the programming of each unit is completed, the programmer examines the program for errors. Only after the programmer is satisfied that the source program correctly implements the detailed design, should the program be compiled. Compiling translates the source program to its machine executable form, the object program.

If the detailed design is in error, is ambiguous, or is not sufficiently complete to permit the programming to continue without

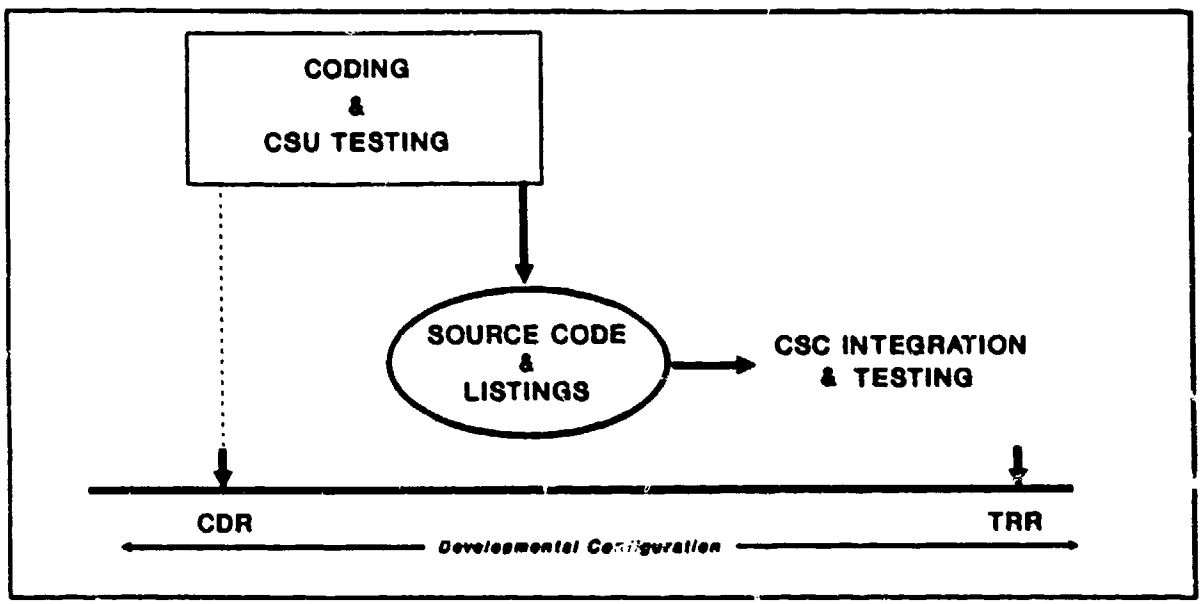


Figure 20-6 Coding and CSU Testing

further definition, the programmer should consult the original designer. The resolution should be documented, and all affected requirements, design, and test documentation updated accordingly.

The purpose of the unit testing activity is to eliminate any errors that may exist in the units as they are programmed. These errors may be due to mistakes by the programmer or deficiencies in the software requirements and design documentation. Usually, the test of a unit is the responsibility of the programmer who programmed the unit. Unit testing is the activity that permits the most control over test conditions and visibility into software behavior. An efficient software development effort requires rigorous unit level test so that most errors are detected before CSC Integration and Test.

Besides producing the source and object code and their respective listings, the contractor develops and records in software development folders the informal test procedures for each unit test as well as the test results. The contractor will usually conduct informal code inspections or walkthroughs on each coded unit and component during several stages of its development. There are no formal reviews scheduled during this step of the development cycle.

20.4.5 CSC Integration and Testing

Once the software is programmed and each unit and component is tested for compliance with its design requirements, the contractor should begin CSC Integration and Testing (Figure 20-7). The purpose of CSC Integration and Testing is to combine the

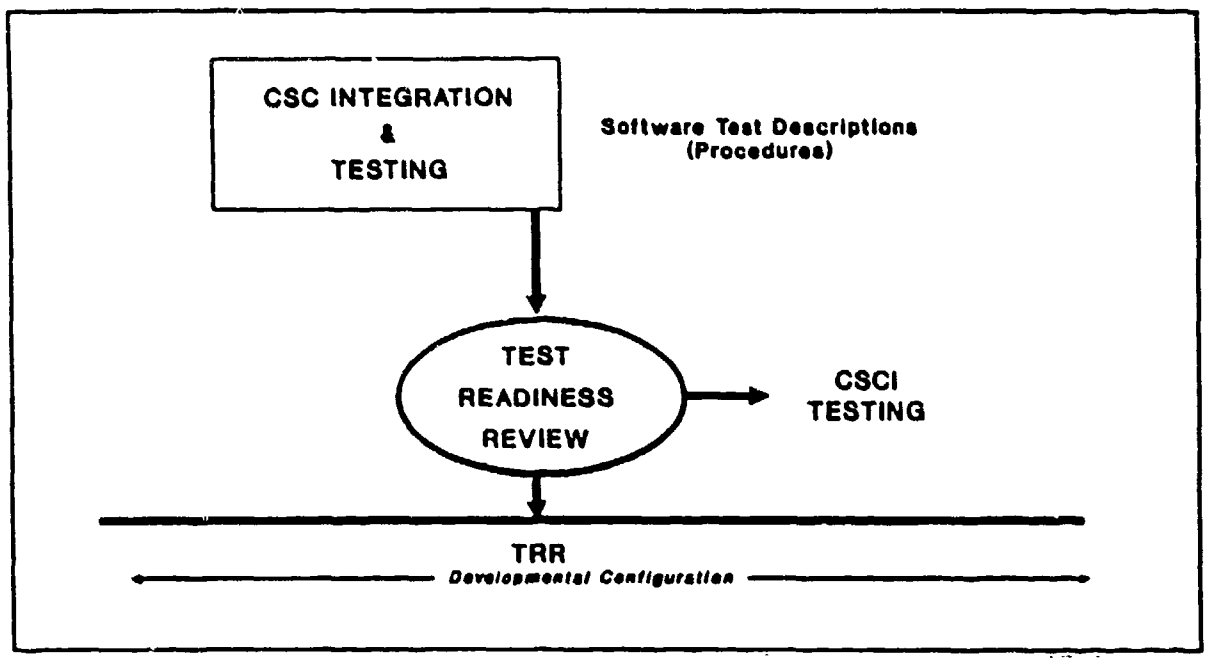


Figure 20-7 CSC Integration and Test

software units and components that have been independently tested into the total software product and to demonstrate that this combination fulfills the system design. The integration is done in a phased manner with only a few components being combined at first, additional ones added after the initial combination has been tested, and the process repeated until all components have been integrated. The phasing of this integration should be based on the functional capabilities that can be demonstrated by specific groups. There may be some overlap with the previous step in that some software components may be ready for integration while others are still being programmed.

Most testing performed during Coding and CSU Testing, and CSC Integration and Testing is called "informal testing". This term doesn't imply that the testing is "casual" or "haphazard", but instead implies that the testing doesn't require government approval. Some formal testing may be accomplished during these steps, but most formal testing is usually accomplished during the next step.

20.4.6 CSCI Testing

After completion of a successful TRR, the contractor will proceed with CSCI Testing (Figure 20-8), the last step of the software development cycle. The purpose is to perform formal tests, in accordance with the software test plans and procedures, on each CSCI and to establish the software Product Baseline. Testing during this step is intended to show that the software satisfies the Software Requirements Specification and the Interface Requirements Specification.

Throughout CSCI testing, the contractor should be updating all previous software documentation, analyzing test data, generating the Software Test Reports (STR), and finalizing the Software Product

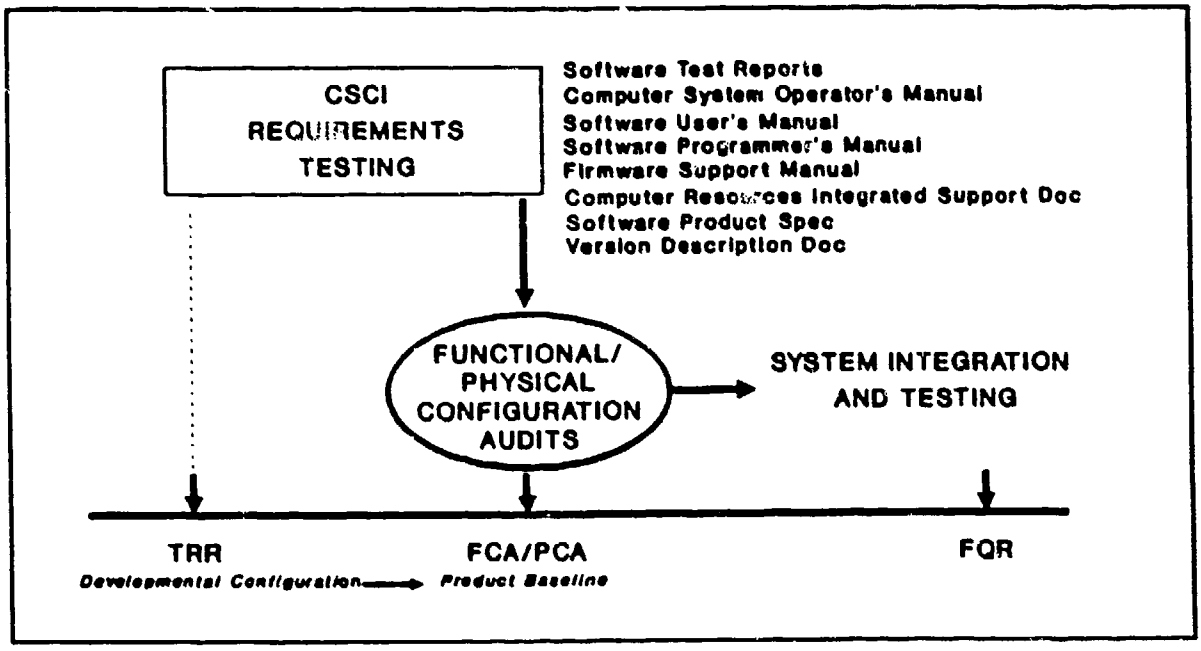


Figure 20-8 CSCI Testing

Specification (SPS) (Type C-5 Specification). This will be the basis for the software product baseline normally established at the PCA, which may immediately follow, or be conducted concurrently with, the FCA for a software only development. Normally, the PCA occurs after the software is released for integration and testing with the system following the software FCA (Figure 20-8). During the software FCA the government verifies that the CSCIs perform in accordance with their respective requirements and interface specifications by examining the test results and reviewing the operational and support documentation. The PCA is the formal technical examination of the as-built software product against its design, including the product specification and the as-coded documentation.

The typical outputs of the contractor's efforts in CSCI Testing are the 1) Software Test Report (STR), 2) operational and support documentation such as the Computer System Operator's Manual (CSOM), the Software Users Manual (SUM), the Software Programmer's Manual (SPM), the Firmware Support Manual (FSM), the Computer Resources Integrated Support Document (CRISD), the Version Description Document (VDD), and 3) the Software Product Specification (SPS). Except for updates and/or revisions, all deliverable documentation should be completed at this time. Figure 20-9 contains a listing of the standardized software documentation, as defined in DOD-STD-2167A [3], that may be required for software development programs.

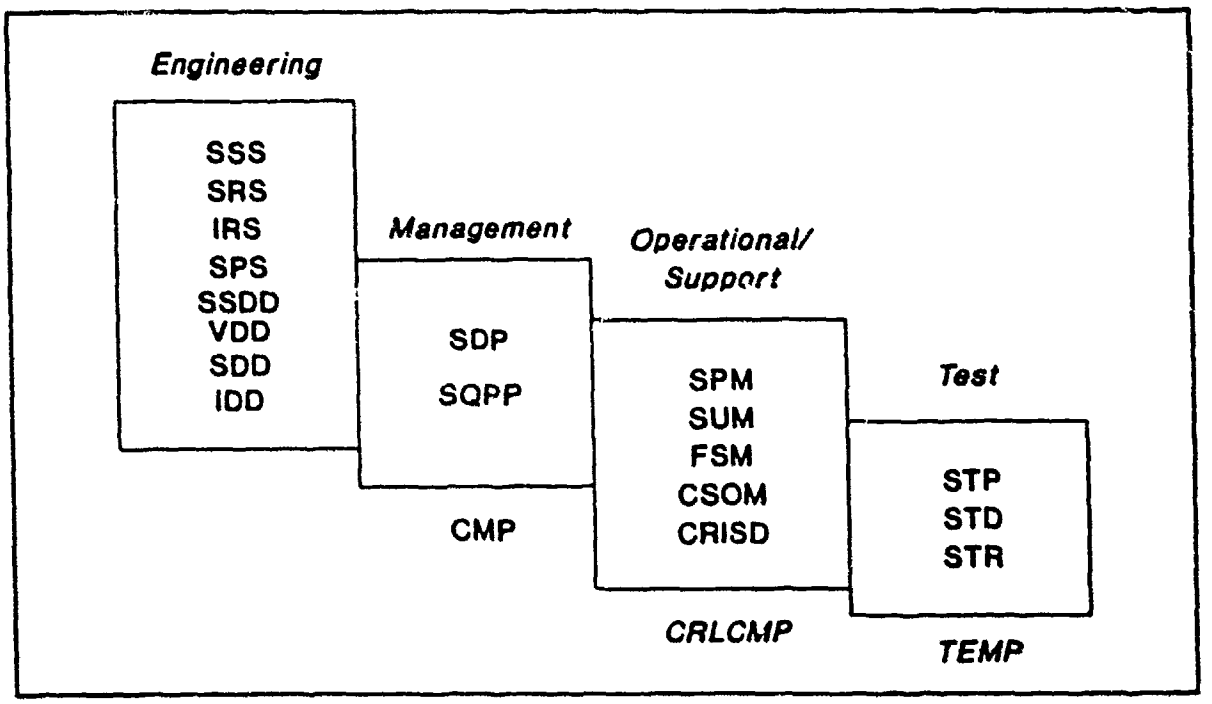


Figure 20-9 Software Products

20.5 SYSTEM INTEGRATION AND TESTING

The purpose of System Integration and Testing is to ensure that the developed software works with the system in the environment that it was designed for (Figure 20-10). The system is turned over to the government after an acceptable Formal Qualification Review (FQR). The FQR is a system-level review that verifies that the actual system performance complies with the system requirements. For computer resources, it addresses the aspects of the software and hardware performance that have been tested after the FCA and PCA. A successful FQR is predicated on a determination that the system meets the specified requirements in the hardware, software and interface specifications.

The contractor's role will diminish significantly subsequent to the FQR. Contractor configuration control of the software should terminate once the product baseline is approved and the government assumes responsibility. All updated documentation, source and object code listings, and all other items stipulated in the contract will be delivered to the government. The government will then assume configuration control responsibility. The contractor, however, will be available to support the government's test and evaluation efforts and to conduct any required acceptance tests.

20.6 TAILORING

The purpose of tailoring is to reduce the overall costs of an acquisition, primarily by reducing the amount and type of documentation being delivered by the contractor and by eliminating redundant or unnecessary testing or procedures. Some questions whose answers will provide

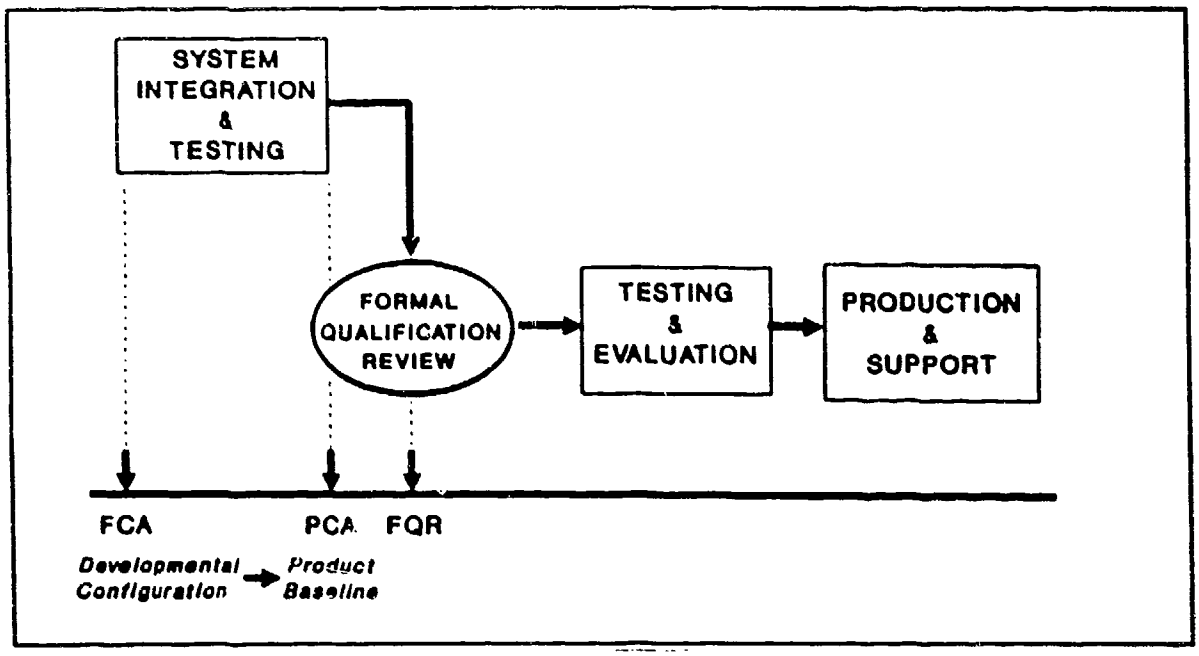


Figure 20-10 System Integration and Test

tailoring guidance are:

a. Is all of the documentation described in DOD-STD- 2167A necessary?

b. What documentation is already available?

c. Is it cost-effective to modify it?

d. Is the contractor's format acceptable?

e. How many copies are actually needed?

f. How can DOD-STD-2167A be tailored?

g. Is a formal design review necessary for each CSCI?

h. How should they be scheduled?

DOD-STD-2167A [3] states that the tailoring process for this standard entails the deletion of non-applicable requirements. But how does a program manager determine which requirements are not applicable? (Figure 20-11 illustrates the tailoring process).

Most tailoring is implemented through the statement of work (SOW). A thorough understanding of requirements (functional, performance, test, documentation) is required in order to properly tailor the standards and specifications.

The first step is to ask if the requirement is appropriate? If not, then tailor it out through the SOW. If the requirement is appropriate, then ask if the requirement is adequate? If it is, then impose the requirement through the SOW. If the requirement is not adequate, ask if the requirement is too restrictive or too

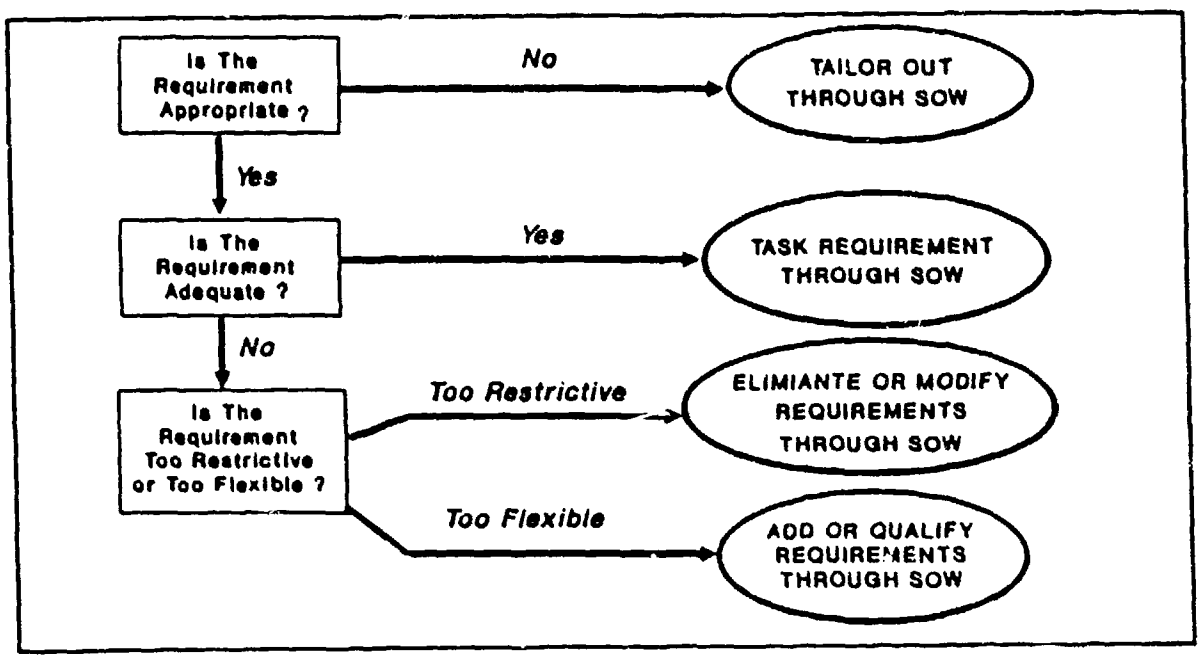


Figure 20-11 Tailoring Process

flexible? If it's too restrictive, delete it or modify it in the SOW. If it's too flexible, add to or modify the requirement in the SOW. Use careful judgement when tailoring a program. Don't tailor areas arbitrarily simply to reduce program costs because in the long run, this may increase life cycle costs.

20.7 ENGINEERING STUDIES

Systems engineering studies are based on the concept of a hierarchy of requirements starting with system level requirements and ending with detailed engineering specifications and data. System definition proceeds by refining each level of requirement into subordinate requirements until the entire system is described. Computer resources are considered as an integral part of the system and are subject to tradeoff and optimization studies. Systems engineering studies will normally include:

a. **Requirements Definition** - Requirements definitions begins with a preliminary allocation of requirements to either hardware or software. The requirements for each software configuration item are documented in a Software Requirements Specification (SRS). The SRS is authenticated at the Software Specification Review (SSR) which is normally held during the FSD phase.

b. **Interface Definition** - The Computer Resources Working Group (CRWG), in conjunction with the Interface Control Working Group, addresses system and subsystem interface requirements that may affect computer resources. The requirements for interfaces between Computer Software Configuration Items (CSCIs) and other system configuration items are documented in one or more Interface Requirements Specifications (IRS) that are also authenticated at the SSR. The SRS and the IRS form the CSCI allocated baseline.

c. **Tradeoff and Optimization** - Tradeoff and optimization studies should consider such issues as:

1) Tradeoffs between computer software and computer hardware

2) Required computer processor architectural features such as memory size, processor speed, input and output capacity, and spare capacity

3) Use of standard equipment, higher order languages, instruction set architectures, and interfaces

4) Alternate approaches for meeting system security requirements

5) Improved supportability versus improved performance

6) Use of existing government resources or commercial off-the-shelf resources versus new development.

d. **Feasibility Studies** - These studies determine the feasibility of alternative allocations of system requirements to computer resources and the derivation of data for formulating budgets and schedules.

e. **Risk Analysis** - The program office must identify the major risks to the software

development effort and insure that plans for managing these risks are incorporated into the system level risk management plan.

f. **Software Support Studies** - Software support studies are conducted to refine the system support concept and to allocate software support requirements. These studies determine how operational system software will be identified. Two potential methods are self-identification of executing software and identification plates affixed to the outside of the computer.

20.8 SUMMARY

Software that is part of a weapon system is managed by partitioning into CSCIs. Each CSCI is managed individually and follows its own software development cycle. Software development activities can be broken down into six steps; any of which can be repeated as many times as necessary during the development cycle. These six steps are Software Requirements Analysis, Preliminary Design, Detailed Design, Coding and CSU Testing, CSC Integration and Testing, and CSCI Testing. These steps typically occur during the Full Scale Development Phase.

DOD-STD-2167A [3] is the approved standard to be used by DOD agencies for software development. It is to be used in conjunction with DOD-STD-2168 [9]. These two standards are not intended to discourage the use of any particular software development method, but instead, aid the software manager in developing and maintaining quality software. They should be used throughout the acquisition life cycle and tailored according to system needs.

It is especially important to develop the product as a system. Never lose sight of the fact that hardware and software development are intimately related. Although they are developed in parallel, software is almost always in the critical path and it is up to the systems engineer to insure proper integration of the two through carefully planned reviews and audits. The talents of an independent verification and validation (IV&V) activity may be used to aid in this process.

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CHAPTER 21

COMPUTER AIDED TECHNICAL MANAGEMENT

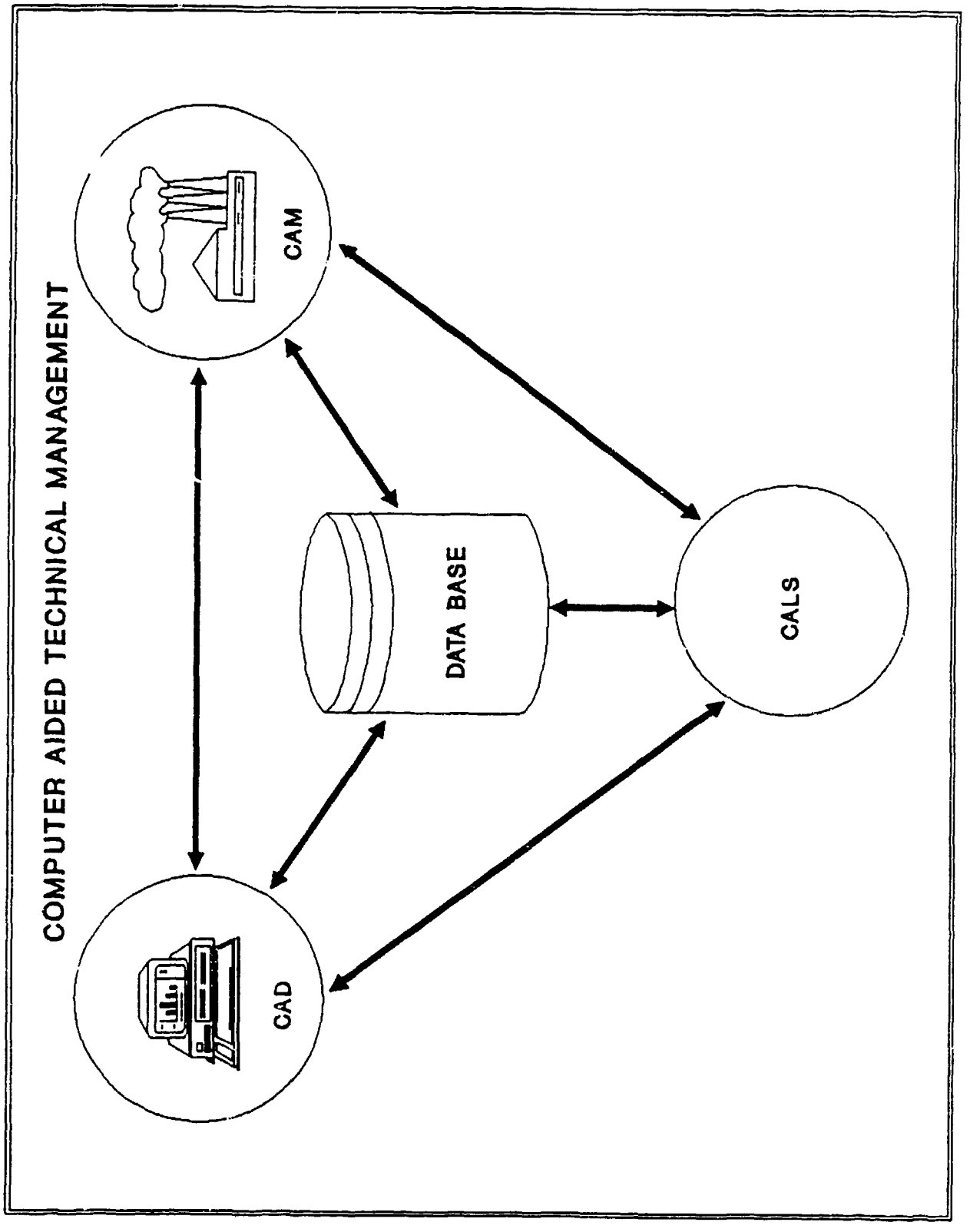
21.1 INTRODUCTION

It is fairly accurate to assume that use of computers and chip-based processors will soon automate a majority of the traditional "*technical management*" functions; thereby, increasing productivity, efficiency, and effectiveness of the engineering community. The Department of Defense (DoD) is encouraging the application of this capability through a variety of incentives and funded programs; e.g., computer aided design (CAD), computer aided manufacturing (CAM), and computer aided acquisition and logistics support (CALS). Industry has led the way in CAD and CAM by linking together the requirements and capabilities of them through a common data base. DoD is attempting to integrate the requirements of CALS into the CAD/CAM structure in order to achieve an integrated computer aided technical management (CATM) system as reflected in Figure 21-1. It is anticipated that the improvements of CATM to the acquisition process will evolve in the same manner that improvements to many development, production, and integration processes have evolved through successful automation. The "*obvious*" direct results of automation will naturally be improvement in both 1) the quality of the products, services, and information that result from these processes and 2) the reduction of the resources required to execute the processes and functions.

In the "*factory of the future*" it is prophesied that a single, integrated, multi-purpose data base will be developed to design, produce, and provide necessary information for the technical management of a product or service acquisition program. Furthermore, it is believed that automatic production machine cells will transform raw materials into finished products without human effort or intervention. Changing from one product to another will require only a change in system software. System support will be more efficient and effective because a common data base will be used for analysis, support system design, configuration control, maintenance data interpretation, and supply support.

To date, after about thirty years of study and research, the most optimistic extents of the "*power of automation*" have proven elusive because of the usual kinds of problems encountered in transition of any new technology from the laboratory to the work place. The following are some examples of these problems:

a. The high initial cost of automation technology increases capital investment payback periods and makes most automation projects unattractive for "bottom line", short term profit oriented managers and enterprises. Because of these high initial costs, automation is perceived to be a significant business risk and a potential cost



Computer Aided Technical Management
Figure 21-1

effectiveness problem; especially, if the automation system is poorly designed, inflexible, or not "user friendly".

b. Expertise in certain engineering technical functions and processes has not proven conducive to transition from people to computers. The requirements of the ***"technical arts"***, which include the knowledge and experience of activities carried out in the transition from design to production and in correction of product defects by integrated product design and manufacturing process changes, will be difficult to translate into the requirements by which machines can execute simply or reliably.

c. Vision based adaptive production line activities (which includes identification, manipulation, assembly, inspection, and adjustment of parts and components into finished complex products) are extremely difficult to analyze and to breakdown into sets of machine executable instructions and routines. It is highly unlikely, from a cost effective perspective, that robots will replace the worker force in the near future. The flexibility and reasoning power of the human cannot yet be achieved through the automation process.

d. Development of integrated systems, capable of many different technical management, engineering, production, and logistics functions (using a single integrated data base), can be very expensive in terms of resource investments. Well designed and innovative single purpose automated systems are available while multiple use systems have not effectively transitioned out of the "design evaluation" stage; therefore, making it difficult to achieve an optimum application of automation technology.

21.2 COMPUTER AIDED TECHNICAL MANAGEMENT (CATM)

Despite the problems mentioned, which have pushed the concepts of the ***"workerless factory"*** and the ***"engineer in the black box"*** away from the near horizon, automation of many technical management functions and engineering processes have been carried out with very encouraging results.

The first computer applications which still provide the greatest productivity improvements and returns on investment with computer automation are those requiring collection, storage, and manipulation of numerical and record type information. Simply stated, any technical management, engineering, or production process which presently is based on paper passing, formula and number crunching, or organization and control will be improved in terms of speed, accuracy, and flexibility by automation. In most cases powerful software systems are available and have been effectively applied to technical management, engineering, and problem solving tasks.

21.2.1 Management Information Systems (MIS)

Resource usage reporting, scheduling, status accounting, and other reporting and recording functions are historically known and used as MIS systems. Also included in this category are so-called decision support systems (DSS) which utilize experiential algorithms to 1) evaluate program management status data and 2) recommend potential corrective actions if required.

These programs are effectively applied to 1) eliminate paper passing between the contractor and the government, 2) reduce delays in change analyses and approvals, 3) implement real time configuration management (CM), 4) track technical performance measurement (TPM) parameters, 5) evaluate logistic support analysis (LSA), and 6) provide a readily accessible, usable, and easily stored program history.

21.2.2 Computer Aided Engineering (CAE)

Computer aided engineering (CAE) is composed of numerous engineering design and analysis programs, collectively known as CAD, CAME/CME (Computer Aided Mechanical Engineering), and CASE (Computer Aided Systems Engineering), which have been successfully developed and widely utilized. These programs 1) incorporate a computer graphics capability to replace the manual hand drawing practice, and 2) create data bases of standard components, previously designed parts, and standard drawing practices and conventions to allow the engineer to produce large quantities of quality drawings and other documentation in short periods of time. The CASE programs have analagous functions in the design of software systems using existing modules and design standards. Theoretical evaluation and analysis of proposed designs in such areas as heat transfer, electrical and anacoic properties and stress reaction can be carried out by including interactive "look up" tables and standard formulae routines. Marginal designs can be eliminated without the expense and delay of fabrication and test. Test and evaluation data and report generation, manipulation, and storage is greatly improved by the use of automated collection systems. Testing can be significantly expedited and organized through the use of programmed testing routines if the program size can support the additional expense of development. The cycle of test, analyze, and fix (TAAF) can be similarly effected by an automated program's speed, analysis power, and rapid design change potential.

21.2.3 Computer Aided Manufacturing (CAM)

CAM and Robotics are in use in many different types of production and manufacturing facilities. Evolution of the Numerical Control (NC) tape controlled machines into Computer Integrated Machining (CIM) cells has taken place in some organizations (raw materials are converted into completed products without human intervention). Experience with robots and CIM has produced some interesting conclusions and rules for effective use of manufacturing automation. Robots have been found to be best applied in simple, repetitive, high volume tasks such as "***put and place***" (e.g.,insertion of electrical components onto circuit boards), especially when the products are designed or redesigned for optimum automatic assembly.

Both robots and CAM are very expensive to acquire and are cost effectively applied only to highly standardized processes and products. One typical example of this general rule is in machining of very high value intricate parts, such as turbine engine cases which are now almost exclusively done

by computer controlled machines.

Many integrated CAD/CAM/CIM systems, in which the CAD data base is interactively used by the CAM/CIM function, are being effectively applied in both government and industry. The Navy is contracting for the development of a multipurpose CAD/CAM system to be used for development of inclusive technical data bases on major systems by all the service commodity commands. Compatibility of this unified government system with the different systems in use by major contractors will be a major issue in future acquisitions.

The general rules regarding robotics and CAD/CAM/CIM application are similar to those regarding MIS systems. In the areas of data management, collection, storage, and manipulation, automatic systems are decisively more productive and effective than human effort and hard copy documentation and should be utilized wherever possible.

Highly standardized manufacturing of low change products in large numbers is also becoming an area with excellent automation payback potential. It should be noted that even in these cases that redesign of the product or the manufacturing process for efficient automation may be required and should always be carried out as a final check before implementation.

As applications proceed toward intricate and difficult multi-axis copying of human motions and adaptive activities such as assembly and adjustment of complicated mechanisms, the payback on investment in robotics and computer controlled manufacturing rapidly diminishes. The sunk costs and time delay of redesign for automated manufacture can be avoided if fiscal and budget stability and product standardization can be established early enough in the program to allow automated manufacturing process design to proceed in parallel with product design and development. This parallel product and process design is encouraged as a matter of policy by DOD and is descriptively called "concurrent engineering". State of the art systems design, typical of DOD acquisitions, and insertion of the latest hardware and software technology should be attempted only by this method.

21.2.4 Computer Aided Acquisition and Logistics Support (CALS)

The most recently proposed automation opportunity of interest to the program management office (PMO) is CALS. CALS is a DOD and industry supported initiative which will enable and accelerate the integration and use of digital technical information development, manipulation, and transfer in the management and functional efforts of weapon system design, evaluation, manufacture, and support. DOD initiated discussions of CALS policy and techniques in 1985 in an attempt to solve the rapidly growing problem and expense of unique and incompatible automated systems used by the government and industry in weapon system acquisition and technical management. CALS will require government organizations and their contractors to adopt specific information exchange standards and to integrate their technical and support information databases. The ultimate goal of CALS are to allow the government to send, receive, distribute, and use technical

information in electronic form. At the present time the Under Secretary of Defense (Acquisition) has requested industry to accept the lead in the development of appropriate standards and efforts to meet the stated CALS goals. The major difficulties at this point are to settle on an agreeable standard and to build confidence and experience in use of automatic data transfer. The next round of problems will include budgeting, system certification and maintenance, , overcoming unwillingness to have real time data transfer and problem exposure, and worker inertia in learning and using the system near its potential. More information on CALS can be found in Chapter 19 of this guide.

21.3 SUMMARY

In evaluating or planning applications of CATM to new acquisition programs, the systems engineer must balance common sense and practical judgement against the estimates of resource costs and returns on investment. At the present time there are no DOD or major industry wide standard systems or system design standards for CAD, CAM, CASE, CIM, CALS, or MIS (advertised as "program management" planning, scheduling, and reporting) systems; however, use of initiative and innovation for automatic digital information transfer, storage, and manipulation, between the government and contractor, is both possible and potentially very productive. Contractor format data and on-line transfer should be evaluated, as a minimum. Investment in a mutually acceptable system and format has been carried out by many recent major DOD and System Commands programs. DOD policy on electronic acquisition data transfer and system standards should be forthcoming in the near future. In the interim, the benefits of automation should justify resource costs to most major programs, with the obvious exception of non development or firm fixed price procurements with minimum data transfer requirements.

The big picture problem for this computer aided revolution is already well documented and accepted- **lack of technically skilled workers.** A long term solution is already in being- **a new generation of workers being raised in the computer aided environment.** Computer aided design and manufacturing are here to stay. They are meely the first steps. Among the tasks remaining to reach the mature integrated system are defining the input-output relationships between the engineering activities (e.g, computer aided technical performance measurement and computer aided cost measurement) and engineering specialties or disciplines. The advancing computer and data systems technologies afford the means to move toward a truly integrated system; but, without a cultural change in the way the functional disciplines interrelate and conduct their activities, true progress will be impeded [1].

21.4 REFERENCES

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APPENDIX A

LIST OF FIGURES

LIST OF FIGURES

APPENDIX B

ACRONYMS

ACRONYMS

ACAT- Acquisition Category (Navy)

ACSN- Advance Change/Study Notice

ADM- Advanced Development Model

ALCM- Air Launched Cruise Missile

BIT- Built-In Test

BITE- Built-In Test Equipment

CCB- Configuration Control Board

CDR- Critical Design Review

CDRL- Contract Data Requirements List

CDS- Concept Description Sheet

C/E- Concept Exploration/ Definition

C_f Consequence of Failure

CI- Configuration Item

CM- Configuration Management

CPM- Cost Performance Measurement

CPR- Cost Performance Report

CRISD- Computer Resources Integrated Support Document

CRLCMP-Computer Resources Life Cycle Management Plan

CSC- Computer Software Component

CSCI- Computer Software Configuration Item

C/SCS- Cost/Schedule Control System

C/SCSC-Cost/Schedule Control System Criteria

CSOM- Computer System Operator's Manual

CSSR- Cost Schedule Status Report

CWBS- Contract Work Breakdown Structure

DAB- Defense Acquisition Board

DCP- Decision Coordinating Paper

DID- Data Item Description

DoD- Department of Defense

DOT&E- Director Operational Test and Evaluation

DS- Design Sheets

DSMC- Defense Systems Management College

DSSP- Defense Standardization and Specification Program

DT- Development Testing

DTC- Design to Cost

DT&E- Development Test and Evaluation

DUSDRE-Deputy Under Secretary of Defense for Research and Engineering

D/V- Concept Demonstration/Validation

ECP- Engineering Change Proposal

ECR- Embedded Computer Resources, Engineering Change Request

EDM- Engineering Development Model

EIMS- End Item Maintenance Sheet

FCA- Functional Configuration Audit

FFBD- Functional Flow Block Diagram

FIS- Facility Interface Sheet

FQR- Formal Qualification Review

FSD- Full Scale Development

GFE- Government-Furnished Equipment

HWCI- Hardware Configuration Item

ICD- Interface Control Document

ICWG- Interface Control Working Group

ILS- Integrated Logistic Support

ILSP- Integrated Logistic Support Plan

IMIP- Industrial Modernization Incentives Program

IOC- Initial Operating Capability

IPS- Integrated Program Summary

IRA- Industrial Resource Analysis

IRN- Interface Revision Notice

IRS- Interface Requirements Specification

LCC- Life Cycle Cost

LCCP- Life Cycle Cost Plan

LLCSC- Lower-Level Computer Software Components

LRIP- Low Rate Initial Production

LRU- Line Replaceable Unit

LSA- Logistic Support Analysis

LSAR- Logistic Support Analysis Record

MCCR- Mission-Critical Computer Resources

MCCS- Mission-Critical Computer System

MM/CC- Milestone Measurement/Cost Correlation

MTBF- Mean Time Between Failure

MTBM- Mean Time Between Maintenance

MTTR- Mean Time To Repair

NATO- North Atlantic Treaty Organization

OCD- Operational Concept Document

OFPP- Office of Federal Procurement Policy

O&M- Operation and Maintenance

OMB- Office of Management and Budget

O&S- Operating and Support, Operation and Support

OSD- Office of the Secretary of Defense

OT- Operational Testing

OTA- Operational Test Agency

OT&E- Operational Test and Evaluation

PAE- Performance Achievement Event

PCA- Physical Configuration Audit

PDM- Program Decision Memorandum

PDR- Preliminary Design Review

PEP- Producibility Engineering and Planning

P_f Probability of Failure

PI- Product Improvement

P^3I- Pre-Planned Product Improvement

PIRN- Preliminary Interface Revision Notice

POM- Program Objectives Memorandum

PRICE- Programmed Review of Information for Costing and Evaluation

PRR- Production Readiness Review

PS- Production Sheet

RAS- Requirements Allocation Sheet

R&D- Research and Development

RDT&E- Research, Development, Test and Evaluation

RFP- Request for Proposal

R&M- Reliability and Maintainability

RAM- Reliability,Availability,Maintainability

SBD- Schematic Block Diagram

SCN- Specification Change Notice

SCP- System Concept Paper

SDR- System Design Review

SE- Systems Engineering

SECDEF-Secretary of Defense

SEMP- Systems Engineering Management Plan

SOW- Statement of Work

SQEP- Software Quality Evaluation Plan

SRR- System Requirements Review

SRS- Software Requirements Specification

SSR- Software Specification Review

STR- Software Test Report

SUM- Software User's Manual

TDRS- Tracking and Data Relay Satellite

T&E- Test and Evaluation

TEMP- Test and Evaluation Master Plan

TLCSC- Top-Level Computer Software Component

TLS- Time Line Sheet

TPM- Technical Performance Measurement

TRACE- Total Risk Assessing Cost Estimates

TRR- Test Requirements Review

TRS- Test Requirements Sheet

TSR- Trade Study Report

WBS- Work Breakdown Structure

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