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FUNDAMENTALS OF SYSTEMS ENGINEERING PART 2

Main Category:	Project Management
Sub Category:	Systems Engineering
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Course Content:	74 pgs
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PRJ-117 EXAM PREVIEW

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Exam Preview:

1. The Work Breakdown Structure (WBS) is a means of organizing system development activities based on system and product decompositions.
   a. True
   b. False
2. According to the reference material, which of the following is NOT a defined effort under Configuration Management Structure?
   a. Identification
   b. Control
   c. Status Accounting
   d. Verification
3. According to the reference material, Engineering Change Proposal (ECP) describes and suggests a change to a configuration base line; uses a Class 1, 2 or 3 system.
   a. True
   b. False
4. According to Chapter 11, which details Technical Reviews and Audits, which type of review occurs in both the requirements and design review of a project?
   a. System requirements review
   b. System functional review
   c. Preliminary design review
   d. Alternative system review
5. According to the reference material, there are 3 classes of simulations: virtual, constructive, and live.
   a. True
   b. False
6. According to Chapter 12, Trade Studies are a formal decision-making methodology used by integrated teams to make choices and resolve conflicts during the systems

engineering process. Using Figure 12-1, which of the following process is done immediately before "Measuring Performance"?

   a. Select and set up methodology
   b. Establish the study problem
   c. Review inputs
   d. Identify and select alternatives

7. According to Figure 14-1, which illustrates the Earned Value Concept, the difference between the BCWP (budgeted cost of work performed) and which other variable would give the user the Cost Variance?
   a. PMB
   b. BCWS
   c. ACWP
   d. Scheduled Variance
8. Supplement 14-A outlines the Technical Performance Measurement methodology used to examine project performance using both actual and projected performance over time. Which of the following terms is defined in the reference material as "Predicted value of parameter at a given point in time?"
   a. Planned value
   b. Planned profile
   c. Tolerance band
   d. Variance
9. According to the reference material, Risk is defined by two characteristics of a possible negative future event: probability of occurrence and consequence of occurrence.
   a. True
   b. False
10. According to the reference material, there are only 3 types of constructive simulations: CAD, CAM and Computer-Aided Systems Engineering.
   a. True
   b. False

PART 3

SYSTEMS ANALYSIS AND CONTROL

CHAPTER 1

INTRODUCTION TO SYSTEMS ENGINEERING MANAGEMENT

1.1 PURPOSE

The overall organization of this text is described in the Preface. This chapter establishes some of the basic premises that are expanded throughout the book. Basic terms explained in this chapter are the foundation for following definitions. Key systems engineering ideas and viewpoints are presented, starting with a definition of a system.

1.2 DEFINITIONS

A System Is …

Simply stated, a system is an integrated composite of people, products, and processes that provide a capability to satisfy a stated need or objective.

Systems Engineering Is…

Systems engineering consists of two significant disciplines: the technical knowledge domain in which the systems engineer operates, and systems engineering management. This book focuses on the process of systems engineering management.

Three commonly used definitions of systems engineering are provided by the best known technical standards that apply to this subject. They all have a common theme:

- A logical sequence of activities and decisions that transforms an operational need into a description of system performance parameters and a preferred system configuration. (MIL-STD-499A, *Engineering Management*, 1 May 1974. Now cancelled.)

- An interdisciplinary approach that encompasses the entire technical effort, and evolves into and verifies an integrated and life cycle balanced set of system people, products, and process solutions that satisfy customer needs. (EIA Standard IS-632, *Systems Engineering*, December 1994.)

- An interdisciplinary, collaborative approach that derives, evolves, and verifies a life-cycle balanced system solution which satisfies customer expectations and meets public acceptability. (IEEE P1220, *Standard for Application and Management of the Systems Engineering Process*, [Final Draft], 26 September 1994.)

In summary, systems engineering is an interdisciplinary engineering management process that evolves and verifies an integrated, life-cycle balanced set of system solutions that satisfy customer needs.

Systems Engineering Management Is…

As illustrated by Figure 1-1, systems engineering management is accomplished by integrating three major activities:

- Development phasing that controls the design process and provides baselines that coordinate design efforts,

- A systems engineering process that provides a structure for solving design problems and

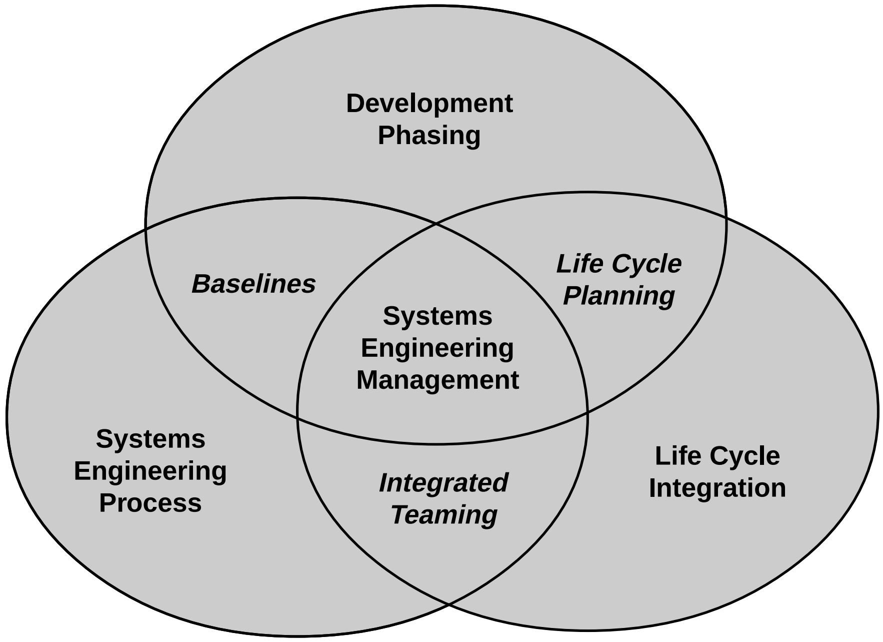

Figure 1-1. Three Activities of Systems Engineering Management

tracking requirements flow through the design effort, and

- Life cycle integration that involves customers in the design process and ensures that the system developed is viable throughout its life.

Each one of these activities is necessary to achieve proper management of a development effort. Phasing has two major purposes: it controls the design effort and is the major connection between the technical management effort and the overall acquisition effort. It controls the design effort by developing design baselines that govern each level of development. It interfaces with acquisition management by providing key events in the development process, where design viability can be assessed. The viability of the baselines developed is a major input for acquisition management Milestone (MS) decisions. As a result, the timing and coordination between technical development phasing and the acquisition schedule is critical to maintain a healthy acquisition program.

The systems engineering process is the heart of systems engineering management. Its purpose is to provide a structured but flexible process that transforms requirements into specifications, architectures, and configuration baselines. The discipline of this process provides the control and traceability to develop solutions that meet customer needs. The systems engineering process may be repeated one or more times during any phase of the development process.

Life cycle integration is necessary to ensure that the design solution is viable throughout the life of the system. It includes the planning associated with product and process development, as well as the integration of multiple functional concerns into the design and engineering process. In this manner, product cycle-times can be reduced, and the need for redesign and rework substantially reduced.

1.3 DEVELOPMENT PHASING

Development usually progresses through distinct levels or stages:

- Concept level, which produces a system concept description (usually described in a concept study);
- System level, which produces a system description in performance requirement terms; and
- Subsystem/Component level, which produces first a set of subsystem and component product performance descriptions, then a set of corresponding detailed descriptions of the products' characteristics, essential for their production.

The systems engineering process is applied to each level of system development, one level at a time, to produce these descriptions commonly called configuration baselines. This results in a series of configuration baselines, one at each development level. These baselines become more detailed with each level.

In the Department of Defense (DoD) the configuration baselines are called the functional baseline for the system-level description, the allocated baseline for the subsystem/ component performance descriptions, and the product baseline for the subsystem/component detail descriptions. Figure 1-2 shows the basic relationships between the baselines. The triangles represent baseline control decision points, and are usually referred to as technical reviews or audits.

Levels of Development Considerations

Significant development at any given level in the system hierarchy should not occur until the configuration baselines at the higher levels are considered complete, stable, and controlled. Reviews and audits are used to ensure that the baselines are ready for the next level of development. As will be shown in the next chapter, this review and audit process also provides the necessary assessment of system maturity, which supports the DoD Milestone decision process.

1.4 THE SYSTEMS ENGINEERING PROCESS

The systems engineering process is a top-down comprehensive, iterative and recursive problem

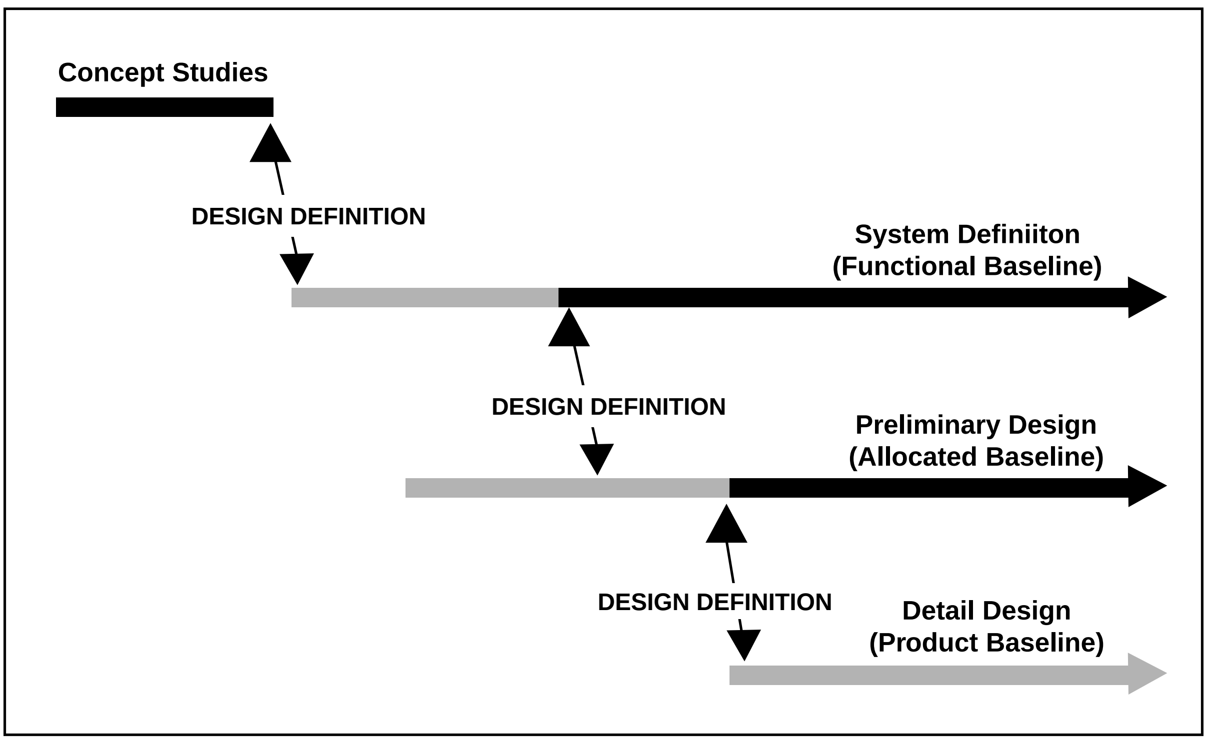

Figure 1-2. Development Phasing

solving process, applied sequentially through all stages of development, that is used to:

- Transform needs and requirements into a set of system product and process descriptions (adding value and more detail with each level of development),
- Generate information for decision makers, and
- Provide input for the next level of development.

As illustrated by Figure 1-3, the fundamental systems engineering activities are Requirements Analysis, Functional Analysis and Allocation, and Design Synthesis—all balanced by techniques and tools collectively called System Analysis and Control. Systems engineering controls are used to track decisions and requirements, maintain technical baselines, manage interfaces, manage risks, track cost and schedule, track technical performance, verify requirements are met, and review/audit the progress.

During the systems engineering process architectures are generated to better describe and understand the system. The word "architecture" is used in various contexts in the general field of engineering. It is used as a general description of how the subsystems join together to form the system. It can also be a detailed description of an aspect of a system: for example, the Operational, System, and Technical Architectures used in Command, Control, Communications, Computers, Intelligence, Surveillance, and Reconnaissance (C4ISR), and software intensive developments. However, Systems Engineering Management as developed in DoD recognizes three universally usable architectures that describe important aspects of the system: functional, physical, and system architectures. This book will focus on these architectures as necessary components of the systems engineering process.

The *Functional Architecture* identifies and structures the allocated functional and performance requirements. The *Physical Architecture* depicts the

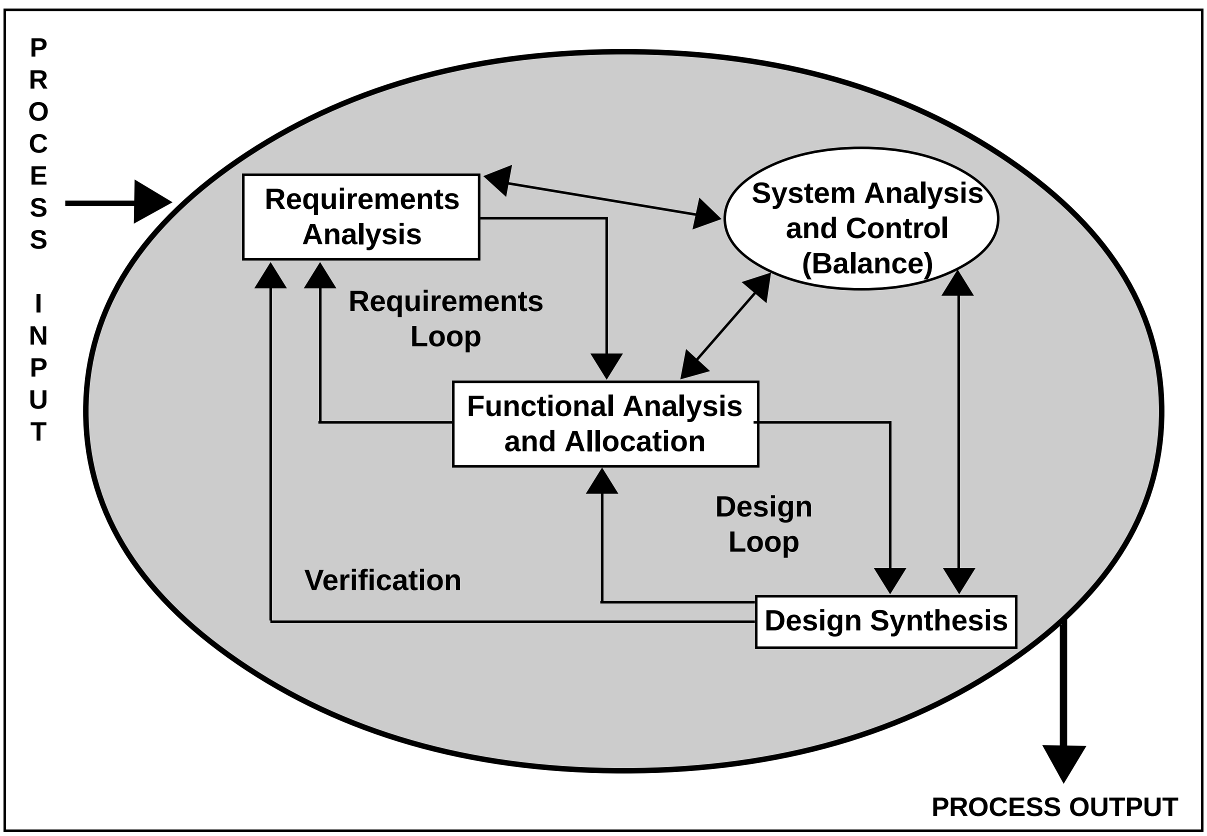

Figure 1-3. The Systems Engineering Process

system product by showing how it is broken down into subsystems and components. The *System Architecture* identifies all the products (including enabling products) that are necessary to support the system and, by implication, the processes necessary for development, production/construction, deployment, operations, support, disposal, training, and verification.

Life Cycle Integration

Life cycle integration is achieved through integrated development—that is, concurrent consideration of all life cycle needs during the development process. DoD policy requires integrated development, called Integrated Product and Product Development (IPPD) in DoD, to be practiced at all levels in the acquisition chain of command as will be explained in the chapter on IPPD. Concurrent consideration of all life cycle needs can be greatly enhanced through the use of interdisciplinary teams. These teams are often referred to as Integrated Product Teams (IPTs).

The objective of an Integrated Product Team is to:

- Produce a design solution that satisfies initially defined requirements, and
- Communicate that design solution clearly, effectively, and in a timely manner.

Multi-functional, integrated teams:

- Place balanced emphasis on product and process development, and
- Require early involvement of all disciplines appropriate to the team task.

Design-level IPT members are chosen to meet the team objectives and generally have distinctive competence in:

- Technical management (systems engineering),
- Life cycle functional areas (eight primary functions),
- Technical specialty areas, such as safety, risk management, quality, etc., or
- When appropriate, business areas such as finance, cost/budget analysis, and contracting.

Life Cycle Functions

Life cycle functions are the characteristic actions associated with the system life cycle. As illustrated by Figure 1-4, they are development, production and construction, deployment (fielding), operation, support, disposal, training, and verification. These activities cover the "cradle to grave" life cycle process and are associated with major functional groups that provide essential support to the life cycle process. These key life cycle functions are commonly referred to as the eight primary functions of systems engineering.

The customers of the systems engineer perform the life-cycle functions. The system user's needs are emphasized because their needs generate the requirement for the system, but it must be remembered that all of the life-cycle functional areas generate requirements for the systems engineering process once the user has established the basic need. ***Those that perform the primary functions also provide life-cycle representation in design-level integrated teams.***

Primary Function Definitions

Development includes the activities required to evolve the system from customer needs to product or process solutions.

Manufacturing/Production/Construction includes the fabrication of engineering test models and "brass boards," low rate initial production, full-rate production of systems and end items, or the construction of large or unique systems or subsystems.

Deployment (Fielding) includes the activities necessary to initially deliver, transport, receive, process, assemble, install, checkout, train, operate, house, store, or field the system to achieve full operational capability.

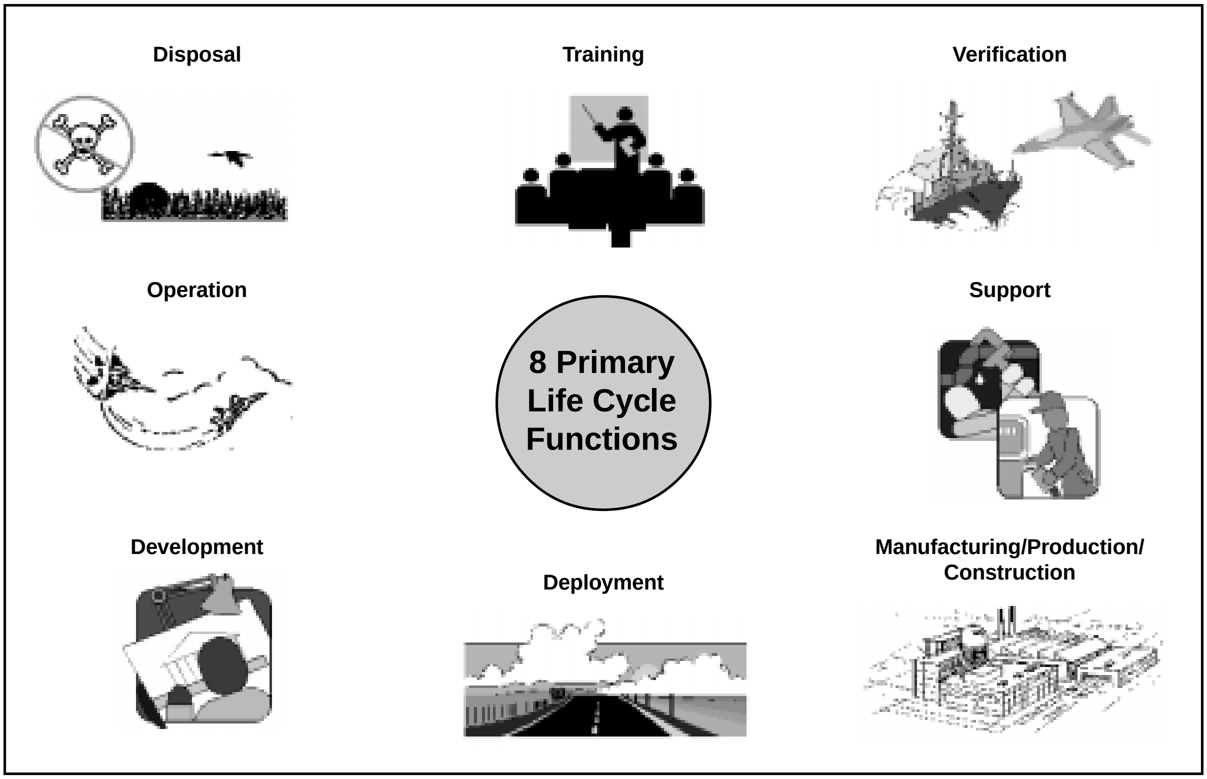

Figure 1-4. Primary Life Cycle Functions

Operation is the user function and includes activities necessary to satisfy defined operational objectives and tasks in peacetime and wartime environments.

Support includes the activities necessary to provide operations support, maintenance, logistics, and material management.

Disposal includes the activities necessary to ensure that the disposal of decommissioned, destroyed, or irreparable system components meets all applicable regulations and directives.

Training includes the activities necessary to achieve and maintain the knowledge and skill levels necessary to efficiently and effectively perform operations and support functions.

Verification includes the activities necessary to evaluate progress and effectiveness of evolving system products and processes, and to measure specification compliance.

Systems Engineering Considerations

Systems engineering is a standardized, disciplined management process for development of system solutions that provides a constant approach to system development in an environment of change and uncertainty. It also provides for simultaneous product and process development, as well as a common basis for communication.

Systems engineering ensures that the correct technical tasks get done during development through planning, tracking, and coordinating. Responsibilities of systems engineers include:

- Development of a total system design solution that balances cost, schedule, performance, and risk,
- Development and tracking of technical information needed for decision making,
- Verification that technical solutions satisfy customer requirements,

- Development of a system that can be produced economically and supported throughout the life cycle,

- Development and monitoring of internal and external interface compatibility of the system and subsystems using an open systems approach,

- Establishment of baselines and configuration control, and

- Proper focus and structure for system and major sub-system level design IPTs.

1.5 GUIDANCE

DoD 5000.2-R establishes two fundamental requirements for program management:

- It requires that an Integrated Product and Process approach be taken to design wherever practicable, and

- It requires that a disciplined systems engineering process be used to translate operational needs and/or requirements into a system solution.

Tailoring the Process

System engineering is applied during all acquisition and support phases for large- and small-scale systems, new developments or product improvements, and single and multiple procurements. The process must be tailored for different needs and/or requirements. Tailoring considerations include system size and complexity, level of system definition detail, scenarios and missions, constraints and requirements, technology base, major risk factors, and organizational best practices and strengths.

For example, systems engineering of software should follow the basic systems engineering approach as presented in this book. However, it must be tailored to accommodate the software development environment, and the unique progress tracking and verification problems software development entails. In a like manner, all technology domains are expected to bring their own unique needs to the process.

This book provides a conceptual-level description of systems engineering management. The specific techniques, nomenclature, and recommended methods are not meant to be prescriptive. Technical managers must tailor their systems engineering planning to meet their particular requirements and constraints, environment, technical domain, and schedule/budget situation.

However, the basic time-proven concepts inherent in the systems engineering approach must be retained to provide continuity and control. For complex system designs, a full and documented understanding of what the system must do should precede development of component performance descriptions, which should precede component detail descriptions. Though some parts of the system may be dictated as a constraint or interface, in general, solving the design problem should start with analyzing the requirements and determining what the system has to do before physical alternatives are chosen. Configurations must be controlled and risk must be managed.

Tailoring of this process has to be done carefully to avoid the introduction of substantial unseen risk and uncertainty. Without the control, coordination, and traceability of systems engineering, an environment of uncertainty results which will lead to surprises. Experience has shown that these surprises almost invariably lead to significant impacts to cost and schedule. Tailored processes that reflect the general conceptual approach of this book have been developed and adopted by professional societies, academia, industry associations, government agencies, and major companies.

1.6 SUMMARY POINTS

- Systems engineering management is a multi-functional process that integrates life cycle functions, the systems engineering problem-solving process, and progressive baselining.

- The systems engineering process is a problem-solving process that drives the balanced development of system products and processes.

- Integrated Product Teams should apply the systems engineering process to develop a life cycle balanced-design solution.

- The systems engineering process is applied to each level of development, one level at a time.

- Fundamental systems engineering activities are Requirements Analysis, Functional Analysis/Allocation, and Design Synthesis, all of which are balanced by System Analysis and Control.

- Baseline phasing provides for an increasing level of descriptive detail of the products and processes with each application of the systems engineering process.

- Baselining in a nut shell is a concept description that leads to a system definition which, in turn, leads to component definitions, and then to component designs, which finally lead to a product.

- The output of each application of the systems engineering process is a major input to the next process application.

CHAPTER 9

WORK BREAKDOWN STRUCTURE

9.1 INTRODUCTION

The Work Breakdown Structure (WBS) is a means of organizing system development activities based on system and product decompositions. The systems engineering process described in earlier chapters produces system and product descriptions. These product architectures, together with associated services (e.g., program management, systems engineering, etc.) are organized and depicted in a hierarchical tree-like structure that is the WBS. (See Figure 9-1.)

Because the WBS is a direct derivative of the physical and systems architectures it could be considered an output of the systems engineering process. It is being presented here as a Systems Analysis and Control tool because of its essential utility for all aspects of the systems engineering process. It is used to structure development activities, to identify data and documents, and to organize integrated teams, and for other non-technical program management purposes.

WBS Role in DoD Systems Engineering

DoD 5000.2-R requires that a program WBS be established to provide a framework for program and technical planning, cost estimating, resource allocation, performance measurement, and status reporting. The WBS is used to define the total system, to display it as a product-oriented family tree composed of hardware, software, services, data, and facilities, and to relate these elements to each other and to the end product. Program offices are to tailor a program WBS using the guidance provided in MIL-HDBK-881.

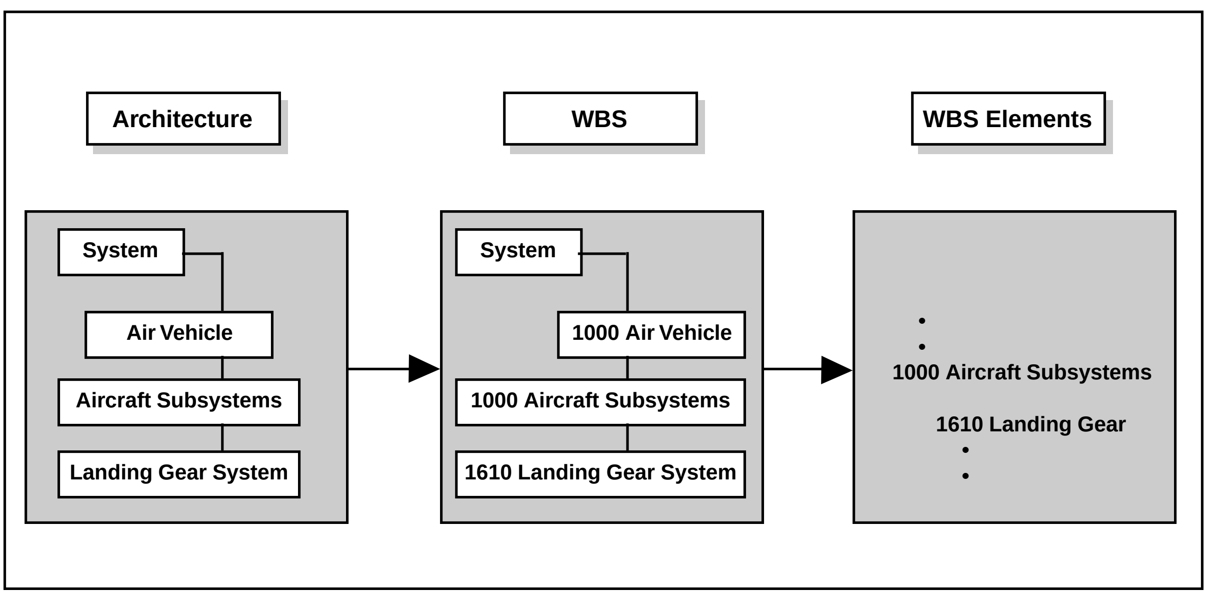

Figure 9–1. Architecture to WBS Flow

The program WBS is developed initially to define the top three levels. As the program proceeds through development and is further defined, program managers should ensure that the WBS is extended to identify all high-cost and high-risk elements for management and reporting, while ensuring the contractor has complete flexibility to extend the WBS below the reporting requirement to reflect how work will be accomplished.

Basic Purposes of the WBS

Organizational:
The WBS provides a coordinated, complete, and comprehensive view of program management. It establishes a structure for organizing system development activities, including IPT design, development, and maintenance.

Business:
It provides a structure for budgets and cost estimates. It is used to organize collection and analysis of detailed costs for earned value reports (Cost Performance Reports or Cost/Schedule Control System Criteria reporting).

Technical:
The WBS establishes a structure for:

- Identifying products, processes, and data,
- Organizing risk management analysis and tracking,
- Enabling configuration and data management. It helps establish interface identification and control.
- Developing work packages for work orders and material/part ordering, and
- Organizing technical reviews and audits.

The WBS is used to group product items for specification development, to develop Statements of Work (SOW), and to identify specific contract deliverables.

WBS – Benefits

The WBS allows the total system to be described through a logical breakout of product elements into work packages. A WBS, correctly prepared, will account for all program activity. It links program objectives and activities with resources, facilitates initial budgets, and simplifies subsequent cost reporting. The WBS allows comparison of various independent metrics and other data to look for comprehensive trends.

It is a foundation for all program activities, including program and technical planning, event schedule definition, configuration management, risk management, data management, specification preparation, SOW preparation, status reporting and problem analysis, cost estimates, and budget formulation.

9.2 WBS DEVELOPMENT

The physical and system architectures are used to prepare the WBS. The architectures should be reviewed to ensure that all necessary products and services are identified, and that the top-down structure provides a continuity of flow down for all tasks. Enough levels must be provided to identify work packages for cost/schedule control purposes. If too few levels are identified, then management visibility and integration of work packages may suffer. If too many levels are identified, then program review and control actions may become excessively time-consuming.

The first three WBS Levels are organized as:

Level 1 – Overall System
Level 2 – Major Element (Segment)
Level 3 – Subordinate Components (Prime Items)

Levels below the first three represent component decomposition down to the configuration item level. In general, the government is responsible for the development of the first three levels, and the contractor(s) for levels below three.

DoD Practice

In accordance with DoD mandatory procedures in DoD 5000.2-R and common DoD practice as established in MIL-HDBK-881, the program office develops a program WBS and a contract WBS for each contract. The program WBS is the WBS that represents the total system, i.e., the WBS that describes the system architecture. The contract WBS is the part of the program WBS that relates to deliverables and tasks of a specific contract.

MIL-HDBK-881 is used by the program office to support the systems engineering process in developing the first three levels of the program WBS, and to provide contractors with guidance for lower level WBS development. As with most standards and handbooks, use of MIL-HDBK-881 cannot be specified as a contract requirement.

Though WBS development is a systems engineering activity, it impacts cost and budget professionals, as well as contracting officers. An integrated team representing these stakeholders should be formed to support WBS development.

WBS Anatomy

A program WBS has an end product part and an enabling product part. The end product part of the system typically consists of the prime mission product(s) delivered to the operational customer. This part of the WBS is based on the physical architectures developed from operational requirements. It represents that part of the WBS involved in product development. Figure 9-2 presents a simple example of a program WBS product part.

The "enabling product" part of the system includes the products and services required to develop, produce, and support the end product(s). This part of the WBS includes the horizontal elements of the system architecture (exclusive of the end products), and identifies all the products and services necessary to support the life cycle needs of the product. Figure 9-3 shows an example of the top three levels of a complete WBS tree.

Contract WBS

A contract WBS is developed by the program office in preparation for contracting for work required to develop the system. It is further developed by the contractor after contract award. The contract WBS is that portion of the program WBS that is specifically being tasked through the contract. A simple example of a contract WBS derived from the program WBS shown in Figure 9-2 is provided by Figure 9-4. Figure 9-4, like Figure 9-2, only includes the product part of the contract WBS. A

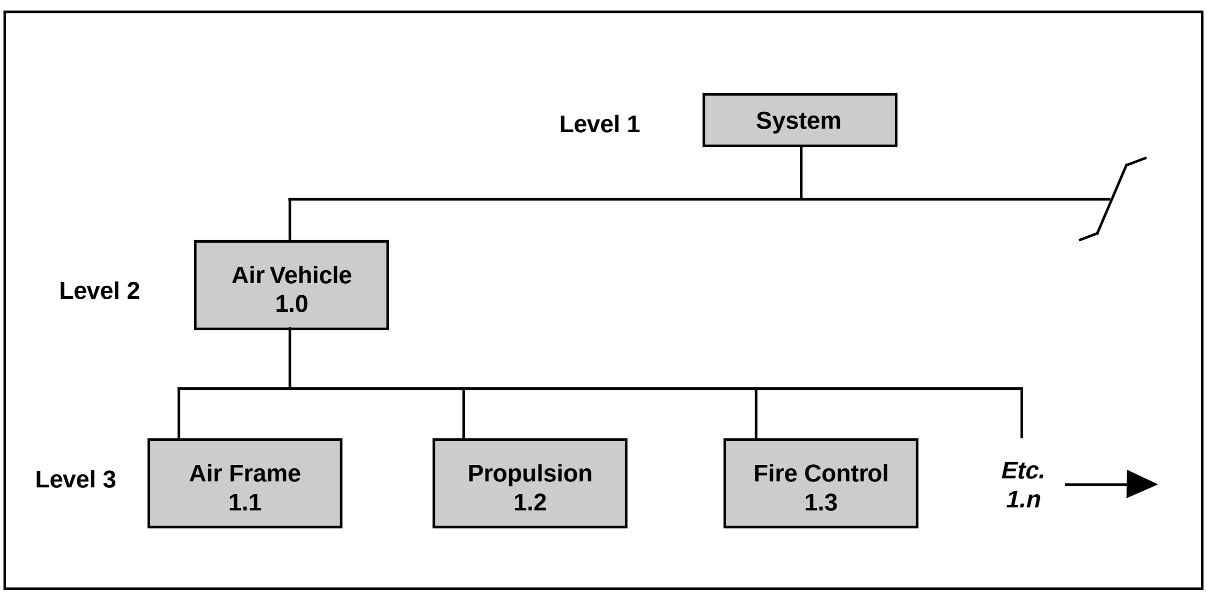

Figure 9-2. Program WBS – The Product Part (Physical Architecture)

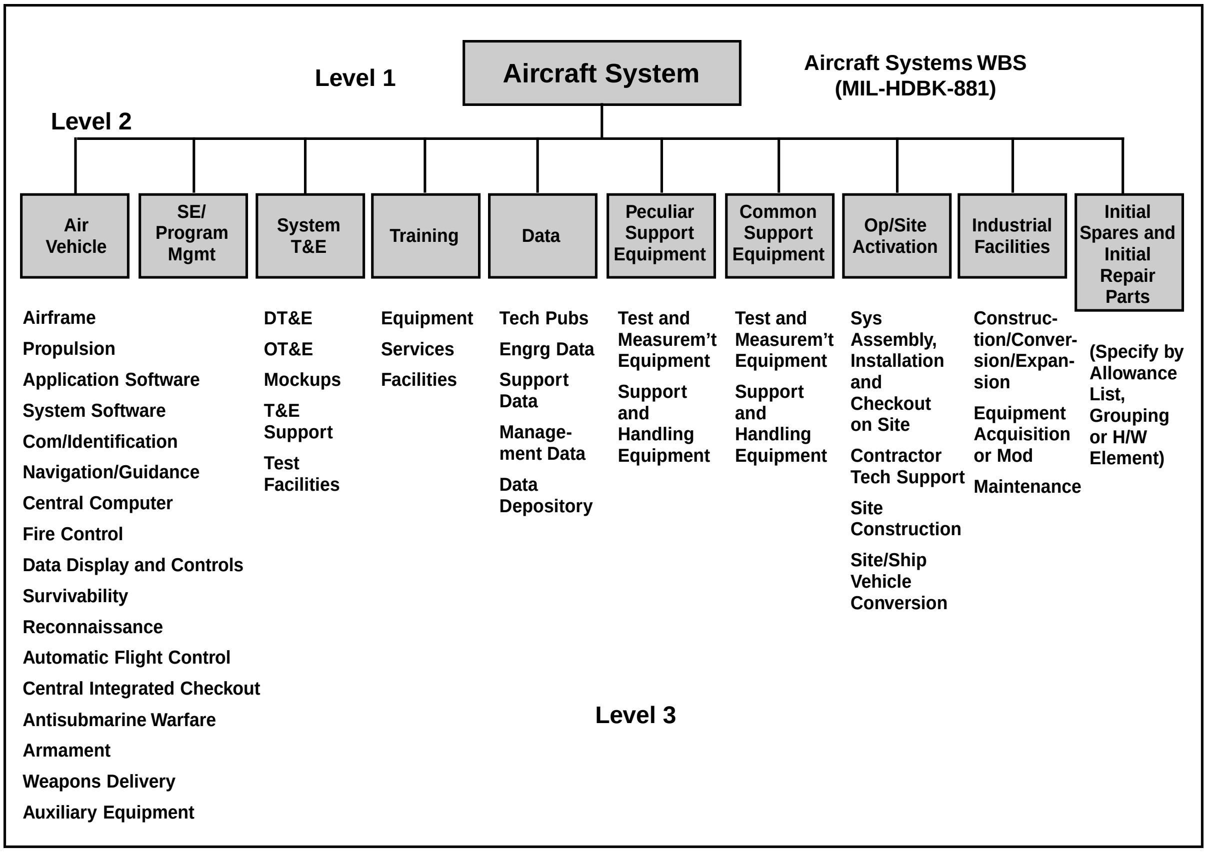

Figure 9-3. The Complete Work Breakdown Structure

complete contract WBS would include associated enabling products, similar to those identified in Figure 9-3. The resulting complete contract WBS is used to organize and identify contractor tasks. The program office's preliminary version is used to develop a SOW for the Request for Proposals.

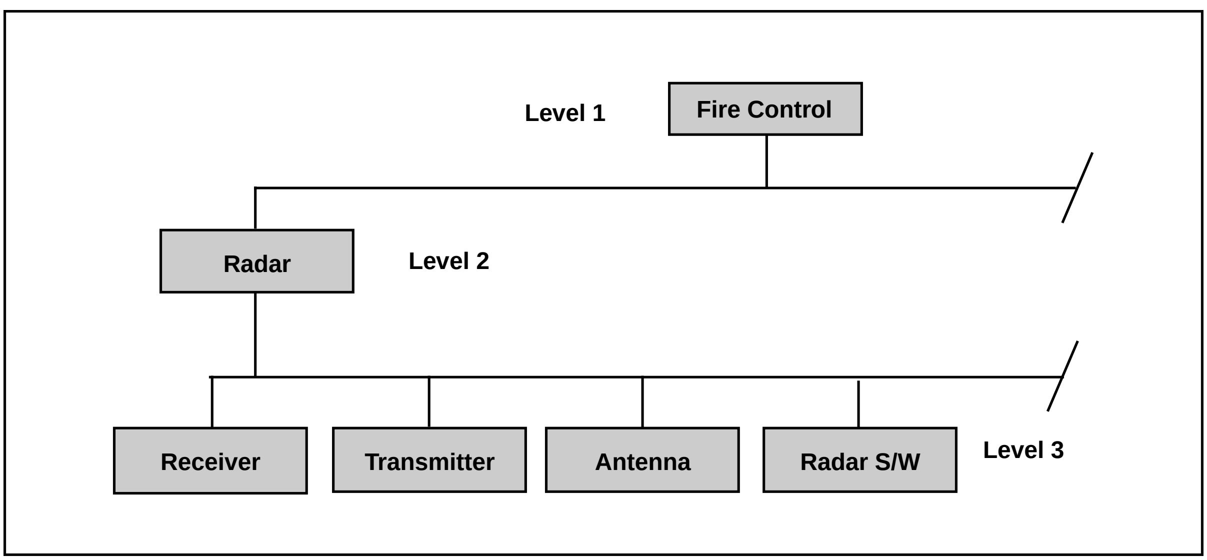

Figure 9–4. Contract WBS

9.3 DESIGNING AND TRACKING WORK

A prime use of the WBS is the design and tracking of work. The WBS is used to establish what work is necessary, a logical decomposition down to work packages, and a method for organizing feedback. As shown by Figure 9-5, the WBS element is matrixed against those organizations in the company responsible for the task. This creates cost accounts and task definition at a detailed level. It allows rational organization of integrated teams and other organizational structures by helping establish what expertise and functional support is required for a specific WBS element. It further allows precise tracking of technical and other management.

WBS Dictionary

As part of the work and cost control use of the WBS, a Work Breakdown Dictionary is developed. For each WBS element a dictionary entry is prepared that describes the task, what costs (activities) apply, and the references to the associated Contract Line Item Numbers and SOW paragraph. An example of a level 2 WBS element dictionary entry is shown as Figure 9-6.

9.4 SUMMARY POINTS

- The WBS is an essential tool for the organization and coordination of systems engineering

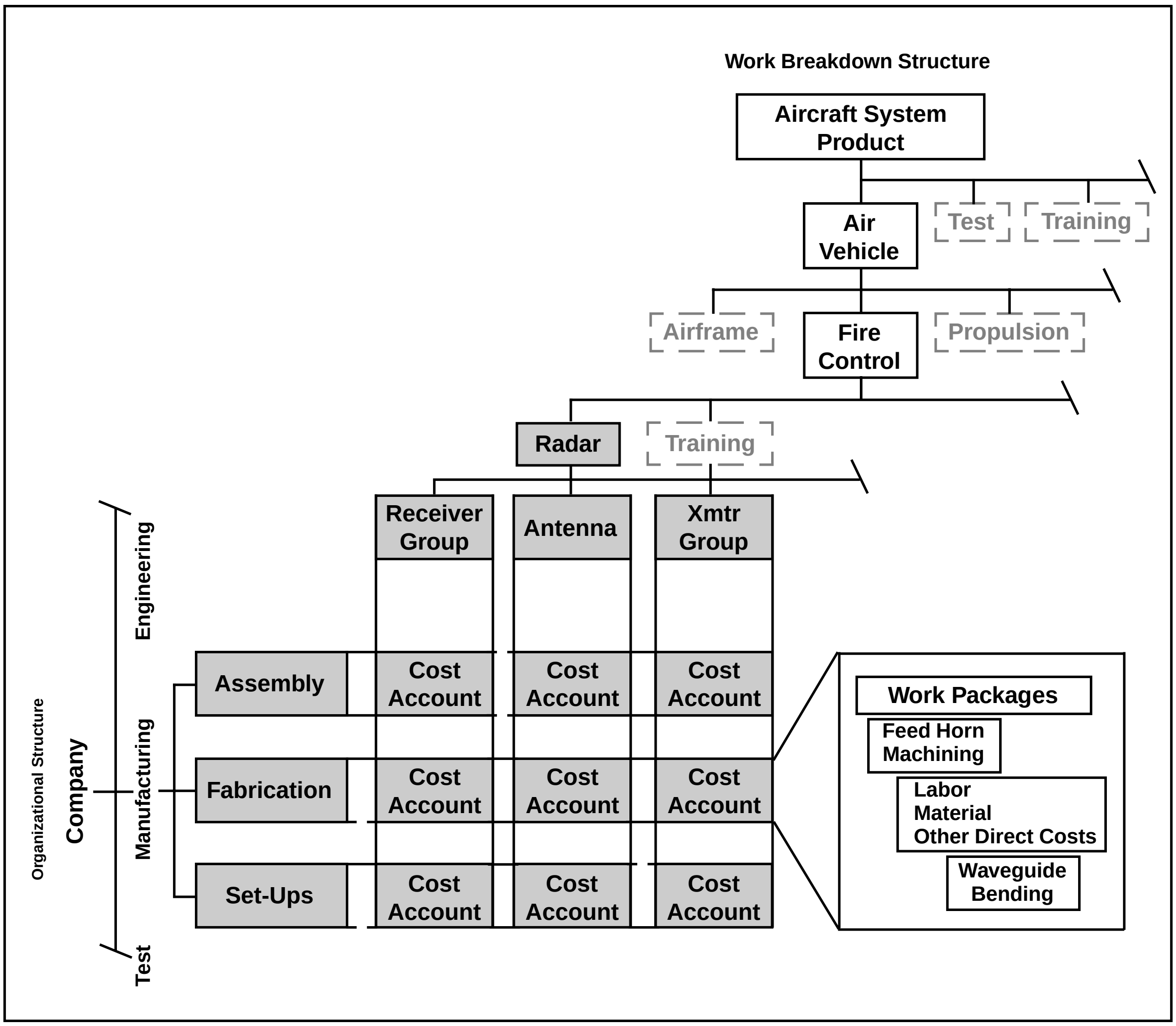

Figure 9-5. WBS Control Matrix

<table>
<tr><td colspan="3">Index Item No. 2</td><td colspan="3">WBS Level 2</td><td>CONTRACT NUMBER
F33657-72-C-0923</td></tr>
<tr><td colspan="3">WBS Element
A10100</td><td colspan="3">WBS Title
Air Vehicle</td><td rowspan="3">Contract
Line Item:
0001, 0001AA, 0001AB, 0001AC, 0001AD
0001AE, 0001AF, 0001AG, 0001AH</td></tr>
<tr><td>Date
Chg</td><td colspan="2">Revision No.</td><td colspan="2">Revision Auth</td><td>Approved</td></tr>
<tr><td colspan="2">Specification No.
689E078780028</td><td colspan="4">Specification Title:
Prime Item Development
Specification for AGM 86A Air Vehicle/
Airframe</td></tr>
<tr><td colspan="6">Element Task Description
Technical Content:
The Air Vehicle element task description refers to the effort required to develop, fabricate, integrate and test the airframe segment, portions of the Navigation/Guidance element, and Airborne Development Test Equipment and Airborne Operational Test Equipment and to the integration assembly and check-out of these complete elements, together with the Engine Segment, to produce the complete Air Vehicle. The lower-level elements included and summarized in the Air Vehicle element are:
Airframe Segment (A11100), Navigation/Guidance Segment (A32100), Airborne Development Test Equipment (A61100), and Airborne Operational Test Equipment (A61200).</td><td>Cost Description
MPC/PMC A10100
Work Order/Work Auth See lower level WBS Elements
Cost Content – System Contractor
The cost to be accumulated against this element includes a summarization of all costs required to plan, develop, fabricate, assemble, integrate and perform development testing, analysis and reporting for the air vehicle. It also includes all costs associated with the required efforts in integrating, assembling and checking our GFP required to create this element.
Applicable SOW Paragraph
3.6.2</td></tr>
</table>

Figure 9-6. Work Breakdown Dictionary

processes, and it is a product of the systems engineering process.

- Its importance extends beyond the technical community to business professionals and contracting officers. The needs of all stakeholders must be considered in its development. The program office develops the program WBS and a high-level contract WBS for each contract. The contractors develop the lower levels of the contract WBS associated with their contract.

- The system architecture provides the structure for a program WBS. SOW tasks flow from this WBS.

- The WBS provides a structure for organizing IPTs and tracking metrics.

CHAPTER 10

CONFIGURATION MANAGEMENT

10.1 FOUNDATIONS

Configuration Defined

A "configuration" consists of the functional, physical, and interface characteristics of existing or planned hardware, firmware, software or a combination thereof as set forth in technical documentation and ultimately achieved in a product. The configuration is formally expressed in relation to a Functional, Allocated, or Product configuration baseline as described in Chapter 8.

Configuration Management

Configuration management permits the orderly development of a system, subsystem, or configuration item. A good configuration management program ensures that designs are traceable to requirements, that change is controlled and documented, that interfaces are defined and understood, and that there is consistency between the product and its supporting documentation. Configuration management provides documentation that describes what is supposed to be produced, what is being produced, what has been produced, and what modifications have been made to what was produced.

Configuration management is performed on baselines, and the approval level for configuration modification can change with each baseline. In a typical system development, customers or user representatives control the operational requirements and usually the system concept. The developing agency program office normally controls the functional baseline. Allocated and product baselines can be controlled by the program office, the producer, or a logistics agent depending on the life cycle management strategy. This sets up a hierarchy of configuration control authority corresponding to the baseline structure. Since lower level baselines have to conform to a higher-level baseline, changes at the lower levels must be examined to assure they do not impact a higher-level baseline. If they do, they must be approved at the highest level impacted. For example, suppose the only engine turbine assembly affordably available for an engine development cannot provide the continuous operating temperature required by the allocated baseline. Then not only must the impact of the change at the lower level (turbine) be examined, but the change should also be reviewed for possible impact on the functional baseline, where requirements such as engine power and thrust might reside.

Configuration management is supported and performed by integrated teams in an Integrated Product and Process Development (IPPD) environment. Configuration management is closely associated with technical data management and interface management. Data and interface management is essential for proper configuration management, and the configuration management effort has to include them.

DoD Application of Configuration Management

During the development contract, the Government should maintain configuration control of the functional and performance requirements only, giving contractors responsibility for the detailed design. (SECDEF Memo of 29 Jun 94.) This implies government control of the Functional (system requirements) Baseline. Decisions regarding whether or not the government will take control of the lower-level baselines (allocated and product baselines), and when ultimately depends on the requirements and strategies needed for the particular program. In general, government control of lower-level baselines, if exercised, will take place late in the development program after design has stabilized.

Configuration Management Planning

When planning a configuration management effort you should consider the basics: what has to be done, how should it be done, who should do it, when should it be done, and what resources are required. Planning should include the organizational and functional structure that will define the methods and procedures to manage functional and physical characteristics, interfaces, and documents of the system component. It should also include statements of responsibility and authority, methods of control, methods of audit or verification, milestones, and schedules. EIA IS-649, National Consensus Standard for Configuration Management, and MIL-HDBK-61 can be used as planning guidance.

Configuration Item (CI)

A key concept that affects planning is the configuration item (CI). CI decisions will determine what configurations will be managed. CIs are an aggregation of hardware, firmware, or computer software, or any of their discrete portions, which satisfies an end-use function and is designated for separate configuration management. Any item required for logistic support and designated for separate procurement is generally identified as CI. Components can be designated CIs because of crucial interfaces or the need to be integrated with operation with other components within or outside of the system. An item can be designated CI if it is developed wholly or partially with government funds, including nondevelopmental items (NDI) if additional development of technical data is required. All CIs are directly traceable to the WBS.

Impact of CI Designation

CI designation requires a separate configuration management effort for the CI, or groupings of related CIs. The decision to place an item, or items, under formal configuration control results in:

- Separate specifications,
- Formal approval of changes,
- Discrete records for configuration status accounting,
- Individual design reviews and configuration audits,
- Discrete identifiers and name plates,
- Separate qualification testing, and
- Separate operating and user manuals.

10.2 CONFIGURATION MANAGEMENT STRUCTURE

Configuration management comprises four interrelated efforts:

- Identification,
- Control,
- Status Accounting, and
- Audits.

Also directly associated with configuration management are data management and interface management. Any configuration management planning effort must consider all six elements.

Identification

Configuration Identification consists of documentation of formally approved baselines and specifications, including:

- Selection of the CIs,
- Determination of the types of configuration documentation required for each CI,

- Documenting the functional and physical characteristics of each CI,
- Establishing interface management procedures, organization, and documentation,
- Issuance of numbers and other identifiers associated with the system/CI configuration structure, including internal and external interfaces, and
- Distribution of CI identification and related configuration documentation.

Configuration Documentation

Configuration documentation is technical documentation that identifies and defines the item's functional and physical characteristics. It is developed, approved, and maintained through three distinct evolutionary increasing levels of detail. The three levels of configuration documentation form the three baselines and are referred to as functional, allocated, and product configuration documentation. These provide the specific technical description of a system or its components at any point in time.

Configuration Control

Configuration Control is the systematic proposal, justification, prioritization, evaluation, coordination, approval or disapproval, and implementation of all approved changes in the configuration of a system/CI after formal establishment of its baseline. In other words, it is how a system (and its CIs) change control process is executed and managed.

Configuration Control provides management visibility, ensures all factors associated with a proposed change are evaluated, prevents unnecessary or marginal changes, and establishes change priorities. In DoD it consists primarily of a change process that formalizes documentation and provides a management structure for change approval.

Change Documents Used for Government Controlled Baselines

There are three types of change documents used to control baselines associated with government configuration management: Engineering Change Proposal, Request for Deviation, and Request for Waivers.

- Engineering Change Proposals (ECP) identify need for a permanent configuration change. Upon approval of an ECP a new configuration is established.
- Requests for Deviation or Waiver propose a temporary departure from the baseline. They allow for acceptance of non-conforming material. After acceptance of a deviation or waiver the documented configuration remains unchanged.

Engineering Change Proposal (ECP)

An ECP is documentation that describes and suggests a change to a configuration baseline. Separate ECPs are submitted for each change that has a distinct objective. To provide advanced notice and reduce paperwork, Preliminary ECPs or Advance Change/Study Notices can be used preparatory to issue of a formal ECP. Time and effort for the approval process can be further reduced through use of joint government and contractor integrated teams to review and edit preliminary change proposals.

ECPs are identified as Class I or Class II. Class I changes require government approval before changing the configuration. These changes can result from problems with the baseline requirement, safety, interfaces, operating/servicing capability, preset adjustments, human interface including skill level, or training. Class I changes can also be used to upgrade already delivered systems to the new configuration through use of retrofit, mod kits, and the like. Class I ECPs are also used to change contractual provisions that do not directly impact the configuration baseline; for example, changes affecting cost, warranties, deliveries, or

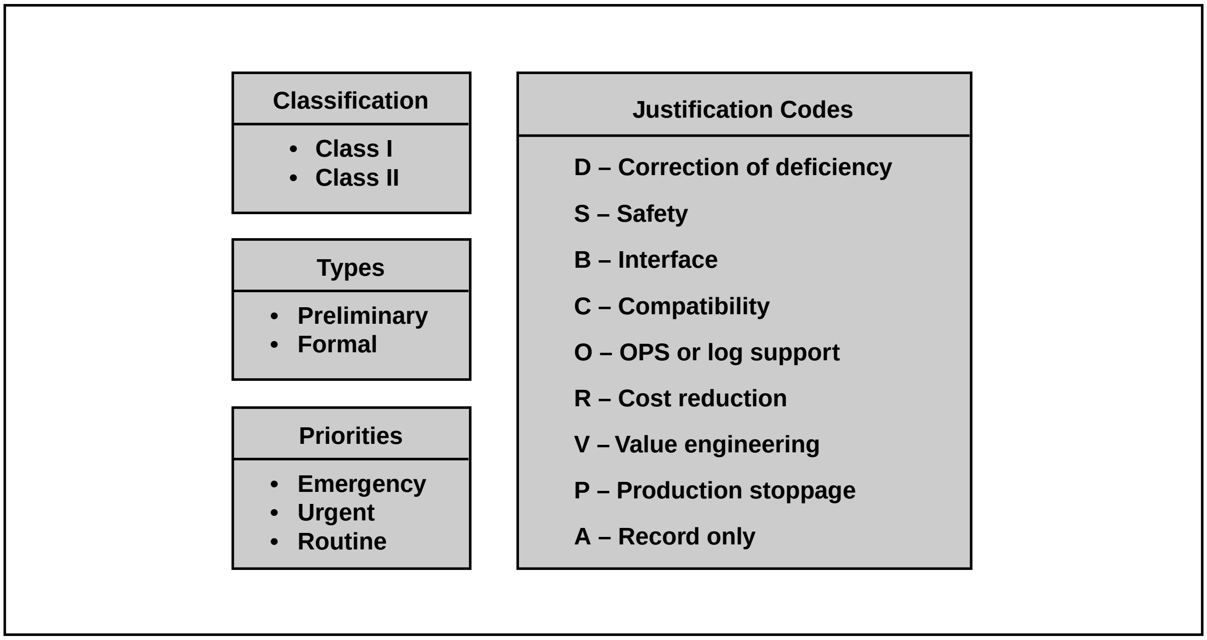

Figure 10-1. ECP Designators

data requirements. Class I ECPs require program office approval, which is usually handled through a formal Configuration Control Board, chaired by the government program manager or delegated representative.

Class II changes correct minor conflicts, typos, and other "housekeeping" changes that basically correct the documentation to reflect the current configuration. Class II applies only if the configuration is not changed when the documentation is changed. Class II ECPs are usually handled by the in-plant government representative. Class II ECPs generally require only that the government concurs that the change is properly classified. Under an initiative by the Defense Contract Management Command (DCMC), contractors are increasingly delegated the authority to make ECP classification decisions.

Figure 10-1 shows the key attributes associated with ECPs. The preliminary ECP, mentioned in Figure 10-1, is a simplified version of a formal ECP that explains the proposed ECP, and establishes an approximate schedule and cost for the change. The expense of an ECP development is avoided if review of the Preliminary ECP indicates the change is not viable. The approach used for preliminary ECPs vary in their form and name. Both Preliminary ECPs and Advanced Change/Study Notices have been used to formalize this process, but forms tailored to specific programs have also been used.

Configuration Control Board (CCB)

A CCB is formed to review Class I ECPs for approval, and make a recommendation to approve or not approve the proposed change. The CCB chair, usually the program manager, makes the final decision. Members advise and recommend, but the authority for the decision rests with the chair. CCB membership should represent the eight primary functions with the addition of representation of the procurement office, program control (budget), and Configuration Control manager, who serves as the CCB secretariat.

The CCB process is shown in Figure 10-2. The process starts with the contractor. A request to the contractor for an ECP or Preliminary ECP is necessary to initiate a government identified configuration change. The secretariat's review process includes assuring appropriate government

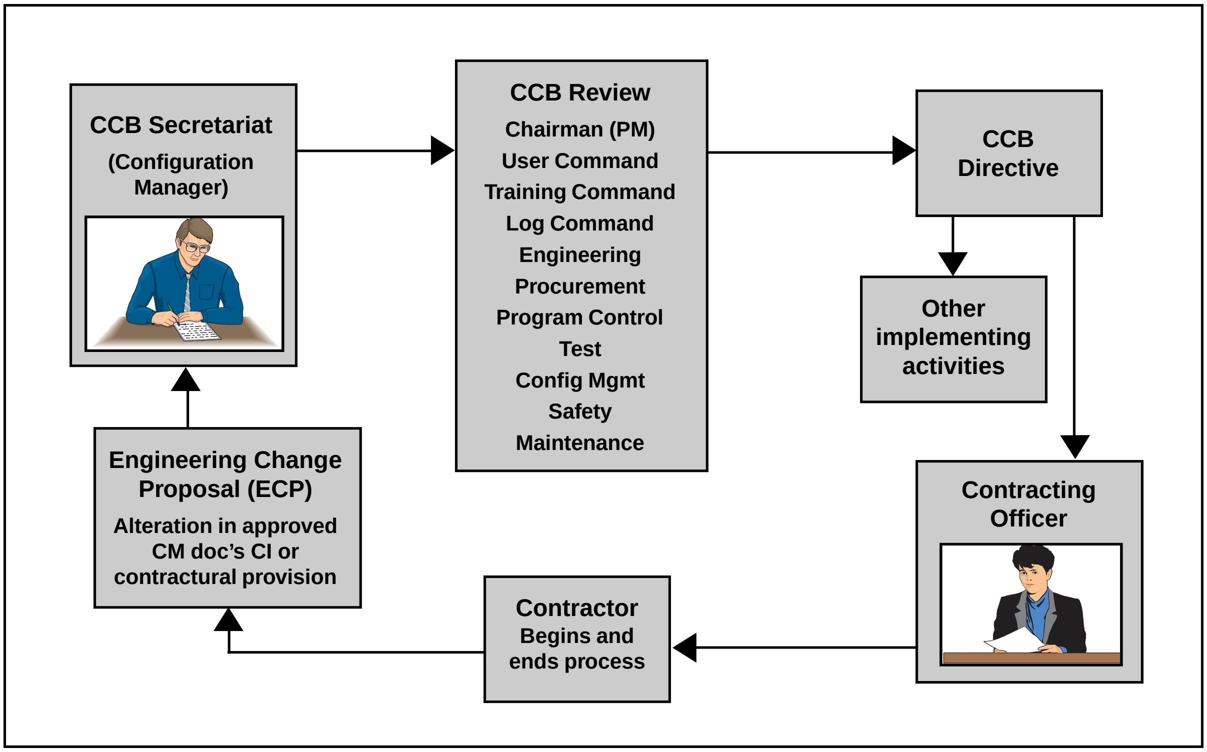

Figure 10-2. Configuration Control Board

contractual and engineering review is done prior to receipt by the CCB.

CCB Management Philosophy

The CCB process is a configuration control process, but it is also a contractual control process. Decisions made by the CCB chair affects the contractual agreement and program baseline as well as the configuration baseline. Concerns over contractual policy, program schedule, and budget can easily come into conflict with concerns relating to configuration management, technical issues, and technical activity scheduling. The CCB technical membership and CCB secretariat is responsible to provide a clear view of the technical need and the impact of alternate solutions to these conflicts. The CCB secretariat is further responsible to see that the CCB is fully informed and prepared, including ensuring that:

- A government/contractor engineering working group has analyzed the ECP and supporting data, prepared comments for CCB consideration, and is available to support the CCB;
- All pertinent information is available for review;
- The ECP has been reviewed by appropriate functional activities; and
- Issues have been identified and addressed.

CCB Documentation

Once the CCB chair makes a decision concerning an ECP, the CCB issues a Configuration Control Board Directive that distributes the decision and identifies key information relating to the implementation of the change:

- Implementation plan (who does what when);
- Contracts affected (prime and secondary);
- Dates of incorporation into contracts;
- Documentation affected (drawings, specifications, technical manuals, etc.), associated cost, and schedule completion date; and

- Identification of any orders or directives needed to be drafted and issued.

Request for Deviation or Waiver

A deviation is a specific written authorization, granted prior to manufacture of an item, to depart from a performance or design requirement for a specific number of units or a specific period of time.

A waiver is a written authorization to accept a CI that departs from specified requirements, but is suitable for use "as is" or after repair.

Requests for deviation and waivers relate to a temporary baseline departure that can affect system design and/or performance. The baseline remains unchanged and the government makes a determination whether the alternative "non-conforming" configuration results in an acceptable substitute. Acceptable substitute usually implies that there will be no impact on support elements, systems affected can operate effectively, and no follow-up or correction is required. The Federal Acquisition Regulations (FAR) requires "consideration" on government contracts when the Government accepts a "non-conforming" unit.

The distinction between Request for Deviation and Request for a Waiver is that a deviation is used *before* final assembly of the affected unit, and a waiver is used *after* final assembly or acceptance testing of the affected unit.

Status Accounting

Configuration Status Accounting is the recording and reporting of the information that is needed to manage the configuration effectively, including:

- A listing of the approved configuration documentation,
- The status of proposed changes, waivers and deviations to the configuration identification,
- The implementation status of approved changes, and
- The configuration of all units, including those in the operational inventory.

Purpose of Configuration Status Accounting

Configuration Status Accounting provides information required for configuration management by:

- Collecting and recording data concerning:
  - Baseline configurations,
  - Proposed changes, and
  - Approved changes.
- Disseminating information concerning:
  - Approved configurations,
  - Status and impact of proposed changes,
  - Requirements, schedules, impact and status of approved changes, and
  - Current configurations of delivered items.

Audits

Configuration Audits are used to verify a system and its components' conformance to their configuration documentation. Audits are key milestones in the development of the system and do not stand alone. The next chapter will show how they fit in the overall process of assessing design maturity.

Functional Configuration Audits (FCA) and the System Verification Review (SVR) are performed in the Production Readiness and LRIP stage of the Production and Development Phase. FCA is used to verify that actual performance of the configuration item meets specification requirements. The SVR serves as system-level audit after FCAs have been conducted.

The Physical Configuration Audit (PCA) is normally held during Rate Production and Development stage as a formal examination of a production representative unit against the draft technical data package (product baseline documentation).

Most audits, whether FCA or PCA, are today approached as a series of "rolling" reviews in which items are progressively audited as they are produced such that the final FCA or PCA becomes significantly less oppressive and disruptive to the normal flow of program development.

10.3 INTERFACE MANAGEMENT

Interface Management consists of identifying the interfaces, establishing working groups to manage the interfaces, and the group's development of interface control documentation. Interface Management identifies, develops, and maintains the external and internal interfaces necessary for system operation. It supports the configuration management effort by ensuring that configuration decisions are made with full understanding of their impact outside of the area of the change.

Interface Identification

An interface is a functional, physical, electrical, electronic, mechanical, hydraulic, pneumatic, optical, software, or similar characteristic required to exist at a common boundary between two or more systems, products, or components. Normally, in a contractual relationship the procuring agency identifies external interfaces, sets requirements for integrated teams, and provides appropriate personnel for the teams. The contracted design agent or manufacturer manages internal interfaces; plans, organizes, and leads design integrated teams; maintains internal and external interface requirements; and controls interfaces to ensure accountability and timely dissemination of changes.

Interface Control Working Group (ICWG)

The ICWG is the traditional forum to establish official communications link between those responsible for the design of interfacing systems or components. Within the IPPD framework ICWGs can be integrated teams that establish linkage between interfacing design IPTs, or could be integrated into a system-level engineering working group. Membership of ICWGs or comparable integrated teams should include membership from each contractor, significant vendors, and participating government agencies. The procuring program office (external and selected top-level interfaces) or prime contractor (internal interfaces) generally designates the chair.

Interface Control Documentation (ICD)

Interface Control Documentation includes Interface Control Drawings, Interface Requirements Specifications, and other documentation that depicts physical and functional interfaces of related or co-functioning systems or components. ICD is the product of ICWGs or comparable integrated teams, and their purpose is to establish and maintain compatibility between interfacing systems or components.

Open Systems Interface Standards

To minimize the impact of unique interface designs, improve interoperability, maximize the use of commercial components, and improve the capacity for future upgrade, an open-systems approach should be a significant part of interface control planning. The open-systems approach involves selecting industry-recognized specifications and standards to define system internal and external interfaces. An open system is characterized by:

- Increased use of functional partitioning and modular design to enhance flexibility of component choices without impact on interfaces,
- Use of well-defined, widely used, non-proprietary interfaces or protocols based on standards developed or adopted by industry recognized standards institutions or professional societies, and
- Explicit provision for expansion or upgrading through the incorporation of additional or higher performance elements with minimal impact on the system.

DoD mandatory guidance for information technology standards is in the Joint Technical Architecture.

10.4 DATA MANAGEMENT

Data management documents and maintains the database reflecting system life cycle decisions, methods, feedback, metrics, and configuration control. It directly supports the configuration status accounting process. Data Management governs and controls the selection, generation, preparation, acquisition, and use of data imposed on contractors.

Data Required By Contract

Data is defined as recorded information, regardless of form or characteristic, and includes all the administrative, management, financial, scientific, engineering, and logistics information and documentation required for delivery from the contractor. Contractually required data is classified as one of three types:

- Type I: Technical data
- Type II: Non-technical data
- Type III: One-time use data (technical or non-technical)

Data is acquired for two basic purposes:

- Information feedback from the contractor for program management control, and
- Decision making information needed to manage, operate, and support the system (e.g., specifications, technical manuals, engineering drawings, etc.).

Data analysis and management is expensive and time consuming. Present DoD philosophy requires that the contractor manage and maintain significant portions of the technical data, including the Technical Data Package (TDP). Note that this does *not* mean the government isn't paying for its development or shouldn't receive a copy for post-delivery use. Minimize the TDP cost by requesting the contractor's format (for example, accepting the same drawings they use for production), and asking only for details on items developed with government funds.

Data Call for Government Contracts

As part of the development of an Invitation for Bid or Request for Proposals, the program office issues a letter that describes the planned procurement and asks integrated team leaders and effected functional managers to identify and justify their data requirements for that contract. A description of each data item needed is then developed by the affected teams or functional offices, and reviewed by the program office. Data Item Descriptions, located in the Acquisition Management Systems Data List (AMSDL) (see Chapter 8) can be used for guidance in developing these descriptions.

Concurrent with the DoD policy on specifications and standards, there is a trend to avoid use of standard Data Item Descriptions on contracts, and specify the data item with a unique tailored data description referenced in the Contract Data Requirements List.

10.5 SUMMARY POINTS

- Configuration management is essential to control the system design throughout the life cycle.
- Use of integrated teams in an IPPD environment is necessary for disciplined configuration management of complex systems.
- Technical data management is essential to trace decisions and changes and to document designs, processes and procedures.
- Interface management is essential to ensure that system elements are compatible in terms of form, fit, and function.
- Three configuration baselines are managed:
  - Functional (System level)
  - Allocated (Design To)
  - Product (Build To/As Built)

Configuration management is a shared responsibility between the government and the contractor. Contract manager (CM) key elements are Identification, Control, Status Accounting, and Audits.

CHAPTER 11

TECHNICAL REVIEWS AND AUDITS

11.1 PROGRESS MEASUREMENT

The Systems Engineer measures design progress and maturity by assessing its development at key event-driven points in the development schedule. The design is compared to pre-established exit criteria for the particular event to determine if the appropriate level of maturity has been achieved. These key events are generally known as Technical Reviews and Audits.

A system in development proceeds through a sequence of stages as it proceeds from concept to finished product. These are referred to as "levels of development." Technical Reviews are done after each level of development to check design maturity, review technical risk, and determines whether to proceed to the next level of development. Technical Reviews reduce program risk and ease the transition to production by:

- Assessing the maturity of the design/development effort,
- Clarifying design requirements,
- Challenging the design and related processes,
- Checking proposed design configuration against technical requirements, customer needs, and system requirements,
- Evaluating the system configuration at different stages,
- Providing a forum for communication, coordination, and integration across all disciplines and IPTs,
- Establishing a common configuration baseline from which to proceed to the next level of design, and
- Recording design decision rationale in the decision database.

Formal technical reviews are preceded by a series of technical interchange meetings where issues, problems and concerns are surfaced and addressed. The formal technical review is NOT the place for problem solving, but to verify problem solving has been done; it is a process rather than an event!

Planning

Planning for Technical Reviews must be extensive and up-front-and-early. Important considerations for planning include the following:

- Timely and effective attention and visibility into the activities preparing for the review,
- Identification and allocation of resources necessary to accomplish the total review effort,
- Tailoring consistent with program risk levels,
- Scheduling consistent with availability of appropriate data,
- Establishing event-driven entry and exit criteria,
- Where appropriate, conduct of incremental reviews,
- Implementation by IPTs,

- Review of all system functions, and
- Confirmation that all system elements are integrated and balanced.

The maturity of enabling products are reviewed with their associated end product. Reviews should consider the testability, producibility, training, and supportability for the system, subsystem or configuration item being addressed.

The depth of the review is a function of the complexity of the system, subsystem, or configuration item being reviewed. Where design is pushing state-of-the-art technology the review will require a greater depth than if it is for a commercial off-the-shelf item. Items, which are complex or an application of new technology, will require a more detailed scrutiny.

Planning Tip: Develop a check list of pre-review, review, and post-review activities required. Develop check lists for exit criteria and required level of detail in design documentation. Include key questions to be answered and what information must be available to facilitate the review process. Figure 11-1 shows the review process with key activities identified.

11.2 TECHNICAL REVIEWS

Technical reviews are conducted at both the system level and at lower levels (e.g., sub-system). This discussion will focus on the primary system-level reviews. Lower-level reviews may be thought of as events that support and prepare for the system-level events. The names used in reference to

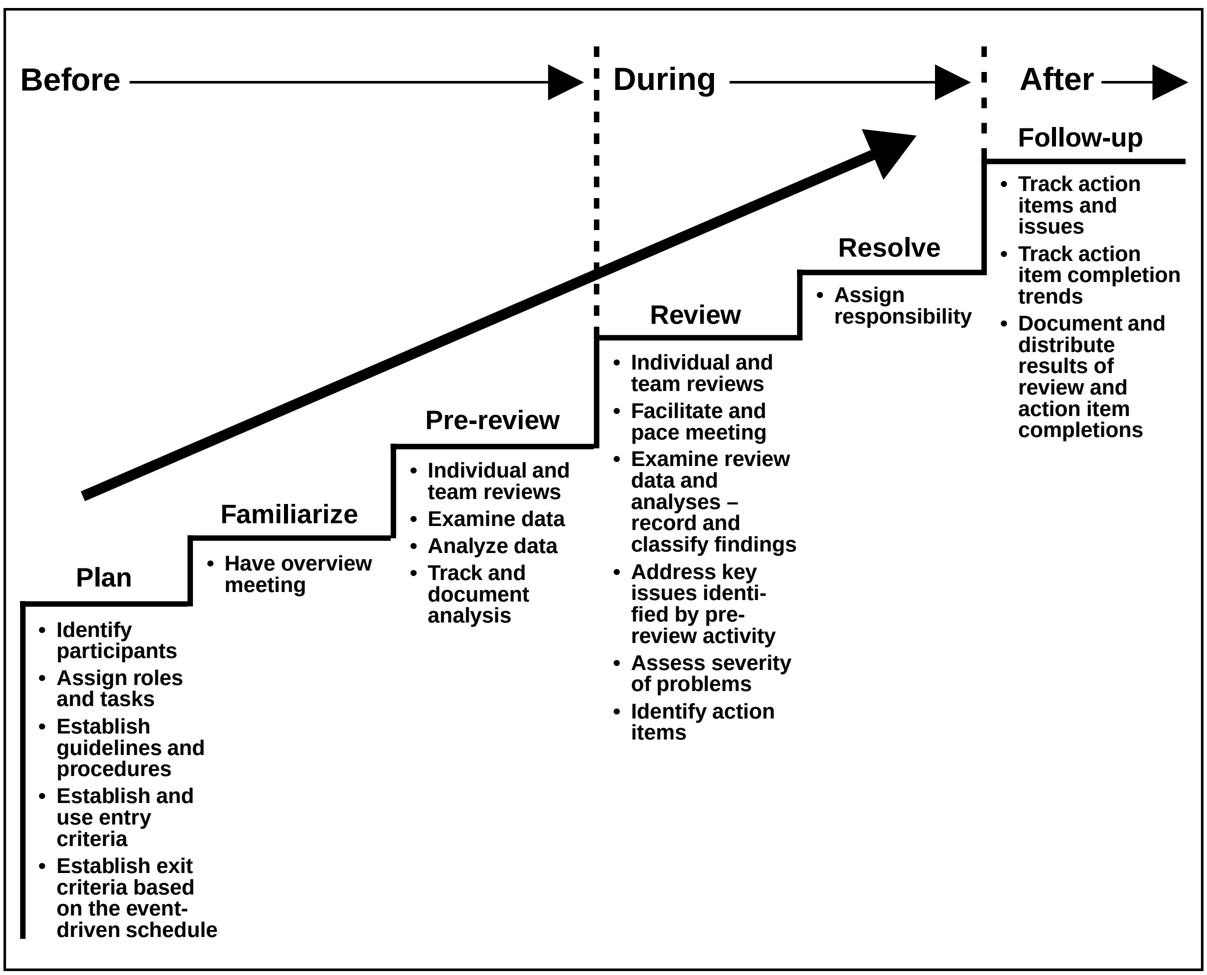

Figure 11-1. Technical Review Process

reviews is unimportant; however, it is important that reviews be held at appropriate points in program development and that both the contractor and government have common expectations regarding the content and outcomes.

Conducting Reviews

Reviews are event-driven, meaning that they are to be conducted when the progress of the product under development merits review. Forcing a review (simply based on the fact that a schedule developed earlier) projected the review at a point in time will jeopardize the review's legitimacy. Do the work ahead of the review event. Use the review event as a confirmation of completed effort. The data necessary to determine if the exit criteria are satisfied should be distributed, analyzed, and analysis coordinated prior to the review. The type of information needed for a technical review would include: specifications, drawings, manuals, schedules, design and test data, trade studies, risk analysis, effectiveness analyses, mock-ups, breadboards, in-process and finished hardware, test methods, technical plans (Manufacturing, Test, Support, Training), and trend (metrics) data. Reviews should be brief and follow a prepared agenda based on the pre-review analysis and assessment of where attention is needed.

Only designated participants should personally attend. These individuals should be those that were involved in the preparatory work for the review and members of the IPTs responsible for meeting the event exit criteria. Participants should include representation from all appropriate government activities, contractor, subcontractors, vendors and suppliers.

A review is the confirmation of a process. New items should not come up at the review. If significant items do emerge, it's a clear sign the review is

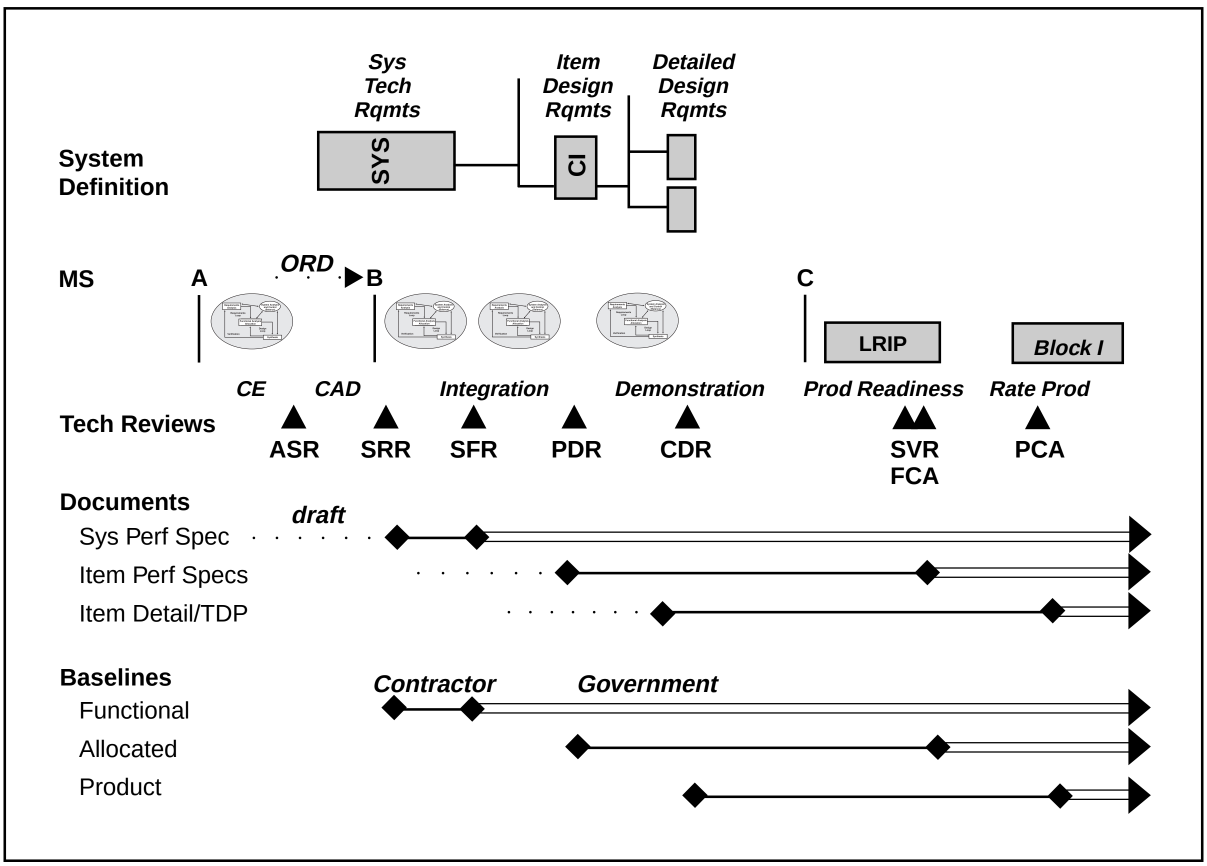

Figure 11-2. Phasing of Technical Reviews

being held prematurely, and project risk has just increased significantly. A poorly orchestrated and performed technical review is a significant indicator of management problems.

Action items resulting from the review are documented and tracked. These items, identified by specific nomenclature and due dates, are prepared and distributed as soon as possible after the review. The action taken is tracked and results distributed as items are completed.

Phasing of Technical Reviews

As a system progresses through design and development, it typically passes from a given level of development to another, more advanced level of development. For example, a typical system will pass from a stage where only the requirements are known, to another stage where a conceptual solution has been defined. Or it may pass from a stage where the design requirements for the primary subsystems are formalized, to a stage where the physical design solutions for those requirements are defined. (See Figure 11-2.)

These stages are the "levels of development" referred to in this chapter. System-level technical reviews are generally timed to correspond to the transition from one level of development to another. The technical review is the event at which the technical manager verifies that the technical maturity of the system or item under review is sufficient to justify passage into the subsequent phase of development, with the concomitant commitment of resources required.

As the system or product progresses through development, the focus of technical assessment takes different forms. Early in the process, the primary focus is on defining the requirements on which subsequent design and development activities will be based. Similarly, technical reviews conducted during the early stages of development are almost always focused on ensuring that the top-level concepts and system definitions reflect the requirements of the user. Once system-level definition is complete, the focus turns to design at sub-system levels and below. Technical reviews during these stages are typically design reviews that establish design requirements and then

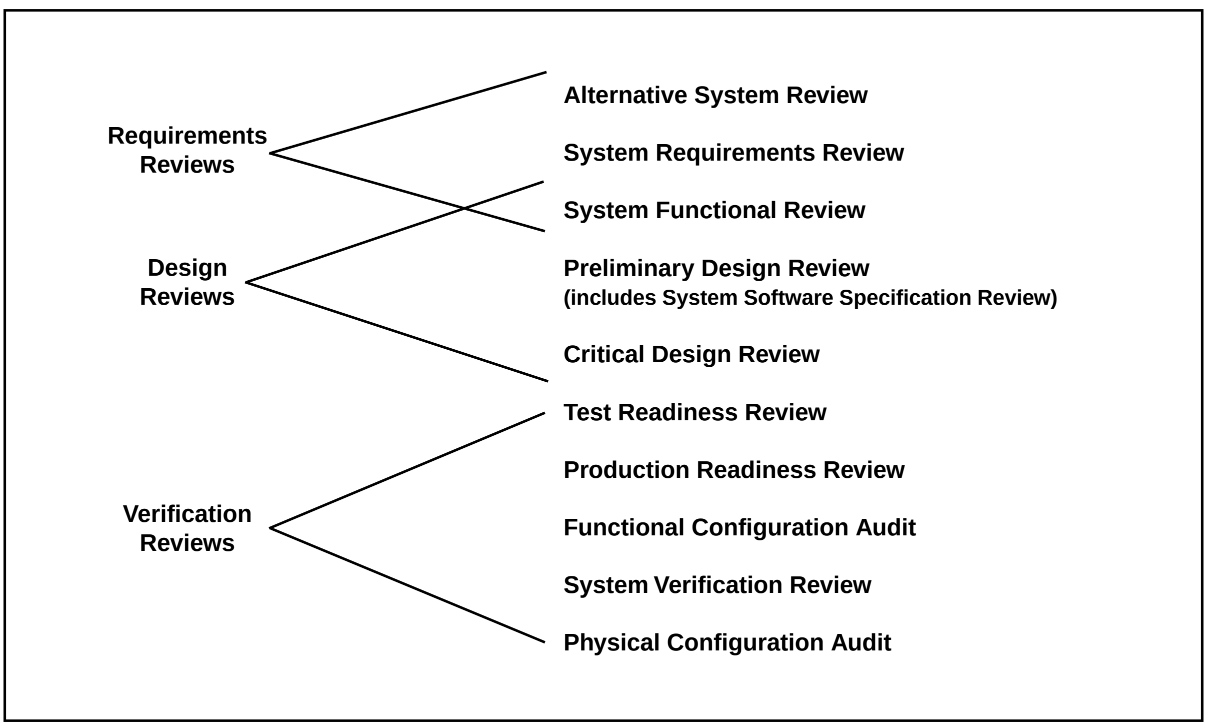

Figure 11-3. Typical System-Level Technical Reviews

verify that physical solutions are consistent with those requirements. In the final stages of development, technical reviews and audits are conducted to verify that the products produced meet the requirements on which the development is based. Figure 11-3 summarizes the typical schedule of system-level reviews by type and focus.

Another issue associated with technical reviews, as well as other key events normally associated with executing the systems engineering process, is when those events generally occur relative to the phases of the DoD acquisition life-cycle process. The timing of these events will vary somewhat from program to program, based upon the explicit and unique needs of the situation; however, Figure 11-4 shows a generalized concept of how the technical reviews normal to systems engineering might occur relative to the acquisition life-cycle phases.

Specific system-level technical reviews are known by many different names, and different engineering standards and documents often use different nomenclature when referring to the same review. The names used to refer to technical reviews are unimportant; however, it is important to have a grasp of the schedule of reviews that is normal to system development and to have an understanding of what is the focus and purpose of those reviews. The following paragraphs outline a schedule of reviews that is complete in terms of assessing technical progress from concept through production. The names used were chosen because they seemed to be descriptive of the focus of the activity. Of course, the array of reviews and the focus of individual reviews is to be tailored to the specific needs of the program under development, so not all programs should plan on conducting all of the following reviews.

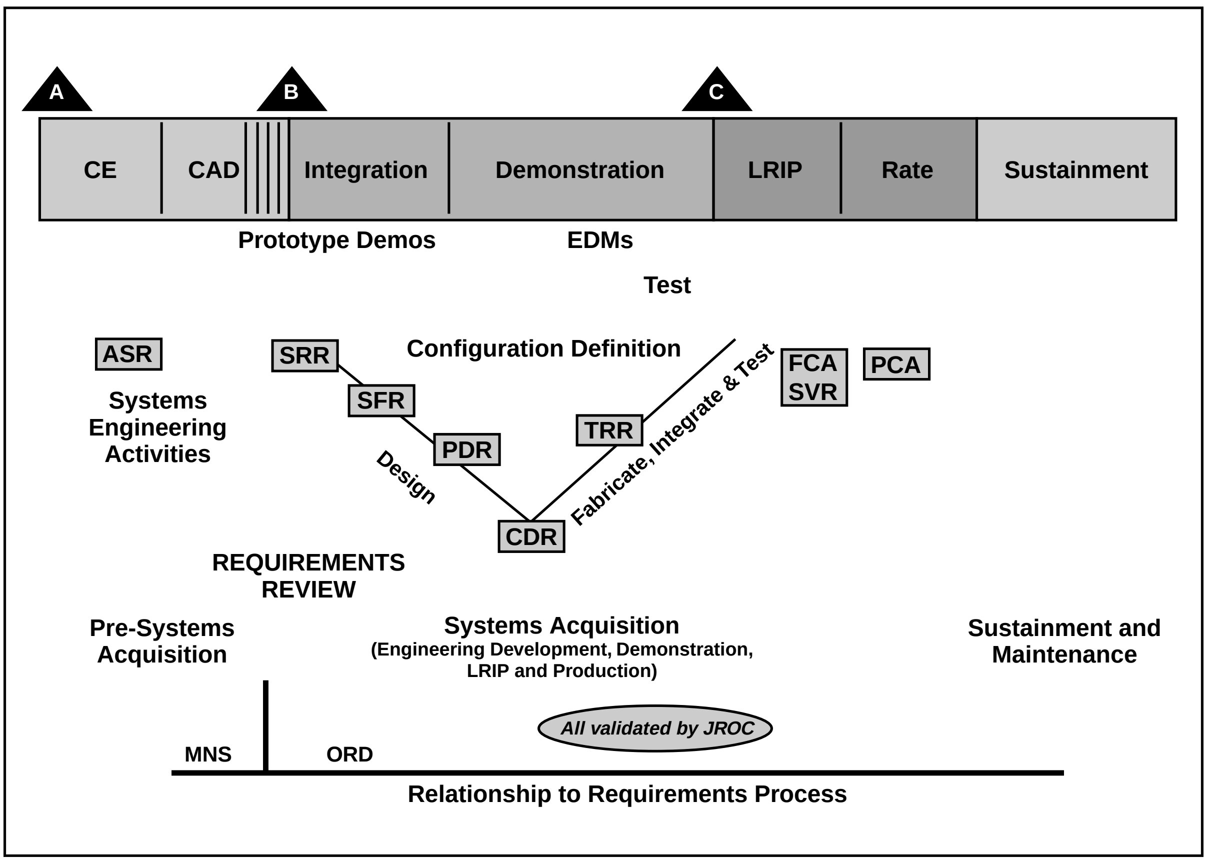

Figure 11-4. Relationship of Systems Engineering Events to Acquisition Life Cycle Phases

Alternative Systems Review (ASR)

After the concept studies are complete a preferred system concept is identified. The associated draft System Work Breakdown Structure, preliminary functional baseline, and draft system specification are reviewed to determine feasibility and risk. Technology dependencies are reviewed to ascertain the level of technology risk associated with the proposed concepts. This review is conducted late during the Concept Exploration stage of the Concept and Technology Development Phase of the acquisition process to verify that the preferred system concept:

- Provides a cost-effective, operationally-effective and suitable solution to identified needs,
- Meets established affordability criteria, and
- Can be developed to provide a timely solution to the need at an acceptable level of risk.

The findings of this review are a significant input to decision review conducted after Concept Exploration to determine where the system should enter in the life-cycle process to continue development. This determination is largely based on technology and system development maturity.

It is important to understand that the path of the system through the life-cycle process will be different for systems of different maturities. Consequently, the decision as whether or not to conduct the technical reviews that are briefly described in the following paragraphs is dependent on the extent of design and development required to bring the system to a level of maturity that justifies producing and fielding it.

System Requirements Review (SRR)

If a system architecture system must be developed and a top-down design elaborated, the system will pass through a number of well-defined levels of development, and that being the case, a well-planned schedule of technical reviews is imperative. The Component Advanced Development stage (the second stage of Concept and Technology Development in the revised acquisition life-cycle process) is the stage during which system-level architectures are defined and any necessary advanced development required to assess and control technical risk is conducted. As the system passes into the acquisition process, i.e., passes a Milestone B and enters System Development and Demonstration, it is appropriate to conduct a SRR. The SRR is intended to confirm that the user's requirements have been translated into system specific technical requirements, that critical technologies are identified and required technology demonstrations are planned, and that risks are well understood and mitigation plans are in place. The draft system specification is verified to reflect the operational requirements.

All relevant documentation should be reviewed, including:

- System Operational Requirements,
- Draft System Specification and any initial draft Performance Item Specifications,
- Functional Analysis (top level block diagrams),
- Feasibility Analysis (results of technology assessments and trade studies to justify system design approach),
- System Maintenance Concept,
- Significant system design criteria (reliability, maintainability, logistics requirements, etc.),
- System Engineering Planning,
- Test and Evaluation Master Plan,
- Draft top-level Technical Performance Measurement, and
- System design documentation (layout drawings, conceptual design drawings, selected supplier components data, etc.).

The SRR confirms that the system-level requirements are sufficiently well understood to permit the developer (contractor) to establish an initial system level functional baseline. Once that baseline is established, the effort begins to define the functional, performance, and physical attributes of the items below system level and to allocate them to the physical elements that will perform the functions.

System Functional Review (SFR)

The process of defining the items or elements below system level involves substantial engineering effort. This design activity is accompanied by analysis, trade studies, modeling and simulation, as well as continuous developmental testing to achieve an optimum definition of the major elements that make up the system, with associated functionality and performance requirements. This activity results in two major systems engineering products: the final version of the system performance specification and draft versions of the performance specifications, which describe the items below system level (item performance specifications). These documents, in turn, define the system functional baseline and the draft allocated baseline. As this activity is completed, the system has passed from the level of a concept to a well-defined system design, and, as such, it is appropriate to conduct another in the series of technical reviews.

The SFR will typically include the tasks listed below. Most importantly, the system technical description (Functional Baseline) must be approved as the governing technical requirement before proceeding to further technical development. This sets the stage for engineering design and development at the lower levels in the system architecture. The government, as the customer, will normally take control of and manage the system functional baseline following successful completion of the SFR.

The review should include assessment of the following items. More complete lists are found in standards and texts on the subject.

- Verification that the system specification reflects requirements that will meet user expectations.
- Functional Analysis and Allocation of requirements to items below system level,
- Draft Item Performance and some Item Detail Specifications,
- Design data defining the overall system,
- Verification that the risks associated with the system design are at acceptable levels for engineering development,
- Verification that the design selections have been optimized through appropriate trade study analyses,
- Supporting analyses, e.g., logistics, human systems integration, etc., and plans are identified and complete where appropriate,
- Technical Performance Measurement data and analysis, and
- Plans for evolutionary design and development are in place and that the system design is modular and open.

Following the SFR, work proceeds to complete the definition of the design of the items below system level, in terms of function, performance, interface requirements for each item. These definitions are typically captured in item performance specifications, sometimes referred to as prime item development specifications. As these documents are finalized, reviews will normally be held to verify that the design requirements at the item level reflect the set of requirements that will result in an acceptable detailed design, because all design work from the item level to the lowest level in the system will be based on the requirements agreed upon at the item level. The establishment of a set of final item-level design requirements represents the definition of the allocated baseline for the system. There are two primary reviews normally associated with this event: the Software Specification Review (SSR), and the Preliminary Design Review (PDR).

Software Specification Review (SSR)

As system design decisions are made, typically some functions are allocated to hardware items, while others are allocated to software. A separate specification is developed for software items to describe the functions, performance, interfaces and other information that will guide the design and development of software items. In preparation for the system-level PDR, the system software specification is reviewed prior to establishing the Allocated Baseline. The review includes:

- Review and evaluate the maturity of software requirements,
- Validation that the software requirements specification and the interface requirements specification reflect the system-level requirements allocated to software,
- Evaluation of computer hardware and software compatibility,
- Evaluation of human interfaces, controls, and displays
- Assurance that software-related risks have been identified and mitigation plans established,
- Validation that software designs are consistent with the Operations Concept Document,
- Plans for testing, and
- Review of preliminary manuals.

Preliminary Design Review (PDR)

Using the Functional Baseline, especially the System Specification, as a governing requirement, a preliminary design is expressed in terms of design requirements for subsystems and configuration items. This preliminary design sets forth the functions, performance, and interface requirements that will govern design of the items below system level. Following the PDR, this preliminary design (Allocated Baseline) will be put under formal configuration control [usually] by the contractor. The Item Performance Specifications, including the system software specification, which form the core of the Allocated Baseline, will be confirmed to represent a design that meets the System Specification.

This review is performed during the System Development and Demonstration phase. Reviews are held for configuration items (CIs), or groups of related CIs, prior to a system-level PDR. Item Performance Specifications are put under configuration control (Current DoD practice is for contractors to maintain configuration control over Item Performance Specifications, while the government exercises requirements control at the system level). At a minimum, the review should include assessment of the following items:

- Item Performance Specifications,
- Draft Item Detail, Process, and Material Specifications,
- Design data defining major subsystems, equipment, software, and other system elements,
- Analyses, reports, "ility" analyses, trade studies, logistics support analysis data, and design documentation,
- Technical Performance Measurement data and analysis,
- Engineering breadboards, laboratory models, test models, mockups, and prototypes used to support the design, and
- Supplier data describing specific components.

[Rough Rule of Thumb: ~15% of production drawings are released by PDR. This rule is anecdotal and only guidance relating to an "average" defense hardware program.]

Critical Design Review (CDR)

Before starting to build the production line there needs to be verification and formalization of the mutual understanding of the details of the item being produced. Performed during the System Development and Demonstration phase, this review evaluates the draft Production Baseline ("Build To" documentation) to determine if the system design documentation (Product Baseline, including Item Detail Specs, Material Specs, Process Specs) is satisfactory to start initial manufacturing. This review includes the evaluation of all CIs. It includes a series of reviews conducted for each hardware CI before release of design to fabrication, and each computer software CI before final coding and testing. Additionally, test plans are reviewed to assess if test efforts are developing sufficiently to indicate the Test Readiness Review will be successful. The approved detail design serves as the basis for final production planning and initiates the development of final software code.

[Rough Rule of Thumb: At CDR the design should be at least 85% complete. Many programs use drawing release as a metric for measuring design completion. This rule is anecdotal and only guidance relating to an "average" defense hardware program.]

Test Readiness Review (TRR)

Typically performed during the System Demonstration stage of the System Development and Demonstration phase (after CDR), the TRR assesses test objectives, procedures, and resources testing coordination. Originally developed as a software CI review, this review is increasingly applied to both hardware and software items. The TRR determines the completeness of test procedures and their compliance with test plans and descriptions. Completion coincides with the initiation of *formal* CI testing.

Production Readiness Reviews (PRR)

Performed incrementally during the System Development and Demonstration and during the Production Readiness stage of the Production and Deployment phase, this series of reviews is held to determine if production preparation for the system, subsystems, and configuration items is complete, comprehensive, and coordinated. PRRs are necessary to determine the readiness for production prior to executing a production go-ahead decision. They will formally examine the producibility of the production design, the control over the projected production processes, and adequacy of resources necessary to execute production. Manufacturing risk is evaluated in relationship to product and manufacturing process performance, cost, and schedule. These reviews support acquisition decisions to proceed to Low-Rate Initial Production (LRIP) or Full-Rate Production.

Functional Configuration Audit/ System Verification Review (FCA)/(SVR)

This series of audits and the consolidating SVR re-examines and verifies the customer's needs, and the relationship of these needs to the system and subsystem technical performance descriptions (Functional and Allocated Baselines). They determine if the system produced (including production representative prototypes or LRIP units) is capable of meeting the technical performance requirements established in the specifications, test plans, etc. The FCA verifies that all requirements established in the specifications, associated test plans, and related documents have been tested and that the item has passed the tests, or corrective action has been initiated. The technical assessments and decisions that are made in SVR will be presented to support the full-rate production go-ahead decision. Among the issues addressed:

- Readiness issues for continuing design, continuing verifications, production, training, deployment, operations, support, and disposal have been resolved,
- Verification is comprehensive and complete,
- Configuration audits, including completion of all change actions, have been completed for all CIs,
- Risk management planning has been updated for production,
- Systems Engineering planning is updated for production, and

- Critical achievements, success criteria and metrics have been established for production.

Physical Configuration Audit (PCA)

After full-rate production has been approved, follow-on independent verification (FOT&E) has identified the changes the user requires, and those changes have been corrected on the baseline documents and the production line, then it is time to assure that the product and the product baseline documentation are consistent. The PCA will formalize the Product Baseline, including specifications and the technical data package, so that future changes can only be made through full configuration management procedures. Fundamentally, the PCA verifies the product (as built) is consistent with the Technical Data Package which describes the Product Baseline. The final PCA confirms:

- The subsystem and CI PCAs have been successfully completed,
- The integrated decision database is valid and represents the product,
- All items have been baselined,
- Changes to previous baselines have been completed,
- Testing deficiencies have been resolved and appropriate changes implemented, and
- System processes are current and can be executed.

The PCA is a configuration management activity and is conducted following procedures established in the Configuration Management Plan.

11.3 TAILORING

The reviews described above are based on a complex system development project requiring significant technical evaluation. There are also cases where system technical maturity is more advanced than normal for the phase, for example, where a previous program or an Advanced Technical Concept Demonstration (ACTD) has provided a significant level of technical development applicable to the current program. In some cases this will precipitate the merging or even elimination of acquisition phases. This does not justify elimination of the technical management activities grouped under the general heading of systems analysis and control, nor does it relieve the government program manager of the responsibility to see that these disciplines are enforced. It does, however, highlight the need for flexibility and tailoring to the specific needs of the program under development.

For example, a DoD acquisition strategy that proposes that a system proceed directly into the demonstration stage may skip a stage of the complete acquisition process, but it must not skip the formulation of an appropriate Functional Baseline and the equivalent of an SFR to support the development. Nor should it skip the formulation of the Allocated Baseline and the equivalent of a PDR, and the formulation of the Product Baseline and the equivalent of a CDR. Baselines must be developed sequentially because they document different levels of design requirements and must build on each other. However, the assessment of design and development maturity can be tailored as appropriate for the particular system. Tailored efforts still have to deal with the problem of determining when the design maturity should be assessed, and how these assessments will support the formulation and control of baselines, which document the design requirements as the system matures.

In tailoring efforts, be extremely careful determining the level of system complexity. The system integration effort, the development of a single advanced technology or complex sub-component, or the need for intensive software development may be sufficient to establish the total system as a complex project, even though it appears simple because most subsystems are simple or off-the-shelf.

11.4 SUMMARY POINTS

- Each level of product development is evaluated and progress is controlled by specification development (System, Item Performance, Item Detail, Process, and Material specifications) and technical reviews and audits (ASR, SRR, SDR, SSR, PDR, CDR, TRR, PRR, FCA, SVR, PCA).

- Technical reviews assess development maturity, risk, and cost/schedule effectiveness to determine readiness to proceed.

- Reviews must be planned, managed, and followed up to be effective as an analysis and control tool.

- As the system progresses through the development effort, the nature of design reviews and audits will parallel the technical effort. Initially they will focus on requirements and functions, and later become very product focused.

- After system level reviews establish the Functional Baseline, technical reviews tend to be subsystem and CI focused until late in development when the focus again turns to the system level to determine the system's readiness for production.

CHAPTER 12

TRADE STUDIES

12.1 MAKING CHOICES

Trade Studies are a formal decision making methodology used by integrated teams to make choices and resolve conflicts during the systems engineering process. Good trade study analyses demand the participation of the integrated team; otherwise, the solution reached may be based on unwarranted assumptions or may reflect the omission of important data.

Trade studies identify desirable and practical alternatives among requirements, technical objectives, design, program schedule, functional and performance requirements, and life-cycle costs are identified and conducted. Choices are then made using a defined set of criteria. Trade studies are defined, conducted, and documented at the various levels of the functional or physical architecture in enough detail to support decision making and lead to a balanced system solution. The level of detail of any trade study needs to be commensurate with cost, schedule, performance, and risk impacts.

Both formal and informal trade studies are conducted in any systems engineering activity. Formal trade studies tend to be those that will be used in formal decision forums, e.g., milestone decisions. These are typically well documented and become a part of the decision database normal to systems development. On the other hand, engineering choices at every level involve trade-offs and decisions that parallel the trade study process. Most of these less-formal studies are documented in summary detail only, but they are important in that they define the design as it evolves.

Systems Engineering Process and Trade Studies

Trade studies are required to support decisions throughout the systems engineering process. During requirements analysis, requirements are balanced against other requirements or constraints, including cost. Requirements analysis trade studies examine and analyze alternative performance and functional requirements to resolve conflicts and satisfy customer needs.

During functional analysis and allocation, functions are balanced with interface requirements, dictated equipment, functional partitioning, requirements flowdown, and configuration items designation considerations. Trade studies are conducted within and across functions to:

- Support functional analyses and allocation of performance requirements and design constraints,
- Define a preferred set of performance requirements satisfying identified functional interfaces,
- Determine performance requirements for lower-level functions when higher-level performance and functional requirements can not be readily resolved to the lower-level, and
- Evaluate alternative functional architectures.

During design synthesis, trade studies are used to evaluate alternative solutions to optimize cost, schedule, performance, and risk. Trade studies are conducted during synthesis to:

- Support decisions for new product and process developments versus non-developmental products and processes;
- Establish system, subsystem, and component configurations;
- Assist in selecting system concepts, designs, and solutions (including people, parts, and materials availability);
- Support materials selection and make-or-buy, process, rate, and location decisions;
- Examine proposed changes;
- Examine alternative technologies to satisfy functional or design requirements including alternatives for moderate- to high- risk technologies;
- Evaluate environmental and cost impacts of materials and processes;
- Evaluate alternative physical architectures to select preferred products and processes; and
- Select standard components, techniques, services, and facilities that reduce system life-cycle cost and meet system effectiveness requirements.

During early program phases, for example, during Concept Exploration and functional baseline development, trade studies are used to examine alternative system-level concepts and scenarios to help establish the system configuration. During later phases, trade studies are used to examine lower-level system segments, subsystems, and end items to assist in selecting component part designs. Performance, cost, safety, reliability, risk, and other effectiveness measures must be traded against each other and against physical characteristics.

12.2 TRADE STUDY BASICS

Trade studies (trade-off analyses) are processes that examine viable alternatives to determine which is preferred. It is important that there be criteria established that are acceptable to all members of the integrated team as a basis for a decision. In addition, there must be an agreed-upon approach to measuring alternatives against the criteria. If these principles are followed, the trade study should produce decisions that are rational, objective, and repeatable. Finally, trade study results must be such that they can be easily communicated to customers and decision makers. If the results of a trade study are too complex to communicate with ease, it is unlikely that the process will result in timely decisions.

Trade Study Process

As shown by Figure 12-1, the process of trade-off analysis consists of defining the problem, bounding the problem, establishing a trade-off methodology (to include the establishment of decision criteria), selecting alternative solutions, determining the key characteristics of each alternative, evaluating the alternatives, and choosing a solution:

- Defining the problem entails developing a problem statement including any constraints. Problem definition should be done with extreme care. *After all, if you don't have the right problem, you won't get the right answer.*
- Bounding and understanding the problem requires identification of system requirements that apply to the study.
- Conflicts between desired characteristics of the product or process being studied, and the limitations of available data. Available databases should be identified that can provide relevant, historical "actual" information to support evaluation decisions.
- Establishing the methodology includes choosing the mathematical method of comparison, developing and quantifying the criteria used for comparison, and determining weighting factors (if any). Use of appropriate models and methodology will dictate the rationality, objectivity, and repeatability of the study. Experience has shown that this step can be easily abused

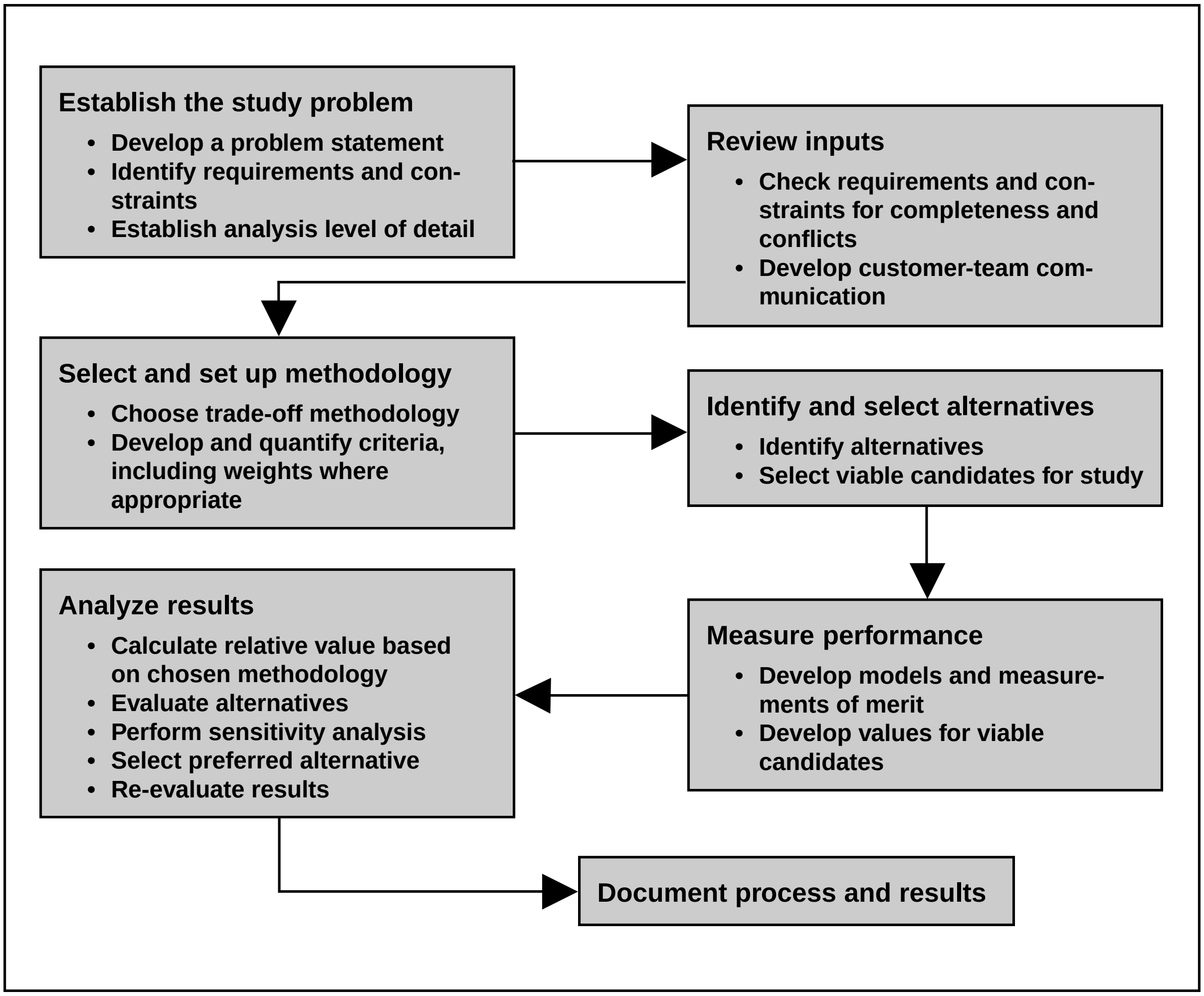

Figure 12-1. Trade Study Process

through both ignorance and design. To the extent possible the chosen methodology should compare alternatives based on true value to the customer and developer. Trade-off relationships should be relevant and rational. Choice of utility or weights should answer the question, "what is the actual value of the increased performance, based on what rationale?"

- Selecting alternative solutions requires identification of all the potential ways of solving the problem and selecting those that appear viable. The number of alternatives can drive the cost of analysis, so alternatives should normally be limited to clearly viable choices.

- Determining the key characteristics entails deriving the data required by the study methodology for each alternative.

- Evaluating the alternatives is the analysis part of the study. It includes the development of a trade-off matrix to compare the alternatives, performance of a sensitivity analysis, selection of a preferred alternative, and a re-evaluation (sanity check) of the alternatives and the study process. Since weighting factors and some "quantified" data can have arbitrary aspects, the sensitivity analysis is crucial. If the solution can be changed with relatively minor changes in data input, the study is probably invalid, and the methodology should be reviewed and revised. After the above tasks are complete, a solution is chosen, documented, and recorded in the database.

Cost Effectiveness Analyses

Cost effectiveness analyses are a special case trade study that compares system or component performance to its cost. These analyses help determine affordability and relative values of alternate solutions. Specifically, they are used to:

- Support identification of affordable, cost optimized mission and performance requirements,
- Support the allocation of performance to an optimum functional structure,
- Provide criteria for the selection of alternative solutions,
- Provide analytic confirmation that designs satisfy customer requirements within cost constraints, and
- Support product and process verification.

12.3 SUMMARY POINTS

- The purpose of trade studies is to make better and more informed decisions in selecting best alternative solutions.
- Initial trade studies focus on alternative system concepts and requirements. Later studies assist in selecting component part designs.
- Cost effectiveness analyses provide assessments of alternative solution performance relative to cost.

SUPPLEMENT 12-A

UTILITY CURVE METHODOLOGY

The utility curve is a common methodology used in DoD and industry to perform trade-off analysis. In DoD it is widely used for cost effectiveness analysis and proposal evaluation.

Utility Curve

The method uses a utility curve, Figure 12-2, for each of the decision factors to normalize them to ease comparison. This method establishes the relative value of the factor as it increases from the minimum value of the range. The curve shows can show a constant value relationship (straight line), increasing value (concave curve), decreasing value (convex curve), or a stepped value.

Decision Matrix

Each of the decision factors will also have relative value between them. These relative values are used to establish weighting factors for each decision factor. The weighting factors prioritize the decision factors and allow direct comparison between them. A decision matrix, similar to Figure 12-3, is generated to evaluate the relative value of the alternative solutions. In the case of Figure 12-3 range is given a weight of 2.0, speed a weight of 1.0, and payload a weight of 2.5. The utility values for each of the decision factors are multiplied by the appropriate weight. The weighted values for each alternative solution are added to obtain a total score for each solution. The solution with the highest score becomes the preferred solution. For the transport analysis of Figure 12-3 the apparent preferred solution is System 3.

Sensitivity

Figure 12-3 also illustrates a problem with the utility curve method. Both the utility curve and

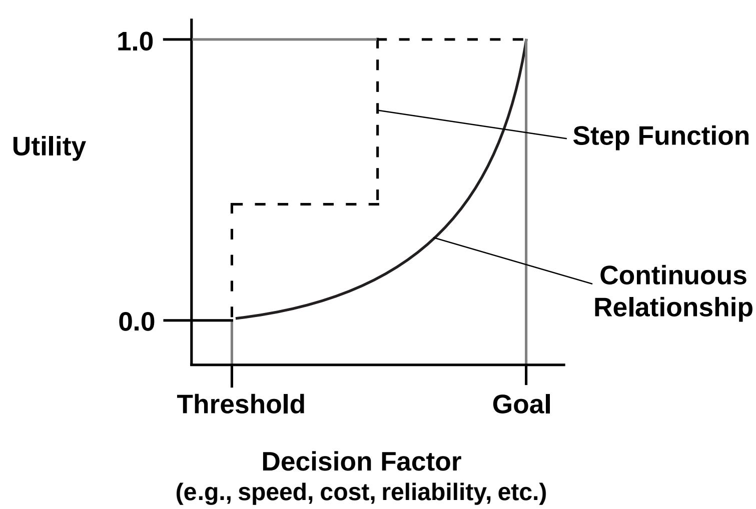

Figure 12-2. Utility Curve

weighting factors contain a degree of judgment that can vary between evaluators. Figure 12-3 shows three systems clustered around 3.8, indicating that a small variation in the utility curve or weighting factor could change the results. In the case of Figure 12-3, a sensitivity analysis should be performed to determine how solutions change as utility and weighting change. This will guide the evaluator in determining how to adjust evaluation criteria to eliminate the problem's sensitivity to small changes. In the case of Figure 12-3 the solution could be as simple as re-evaluating weighting factors to express better the true value to the customer. For example, if the value of range is considered to be less and payload worth more than originally stated, then System 4 may become a clear winner.

Notes

When developing or adjusting utility curves and weighting factors, communication with the customers and decision makers is essential. Most sensitivity problems are not as obvious as Figure 12-3. Sensitivity need not be apparent in the alternatives' total score. To ensure study viability, sensitivity analysis should always be done to examine the consequences of methodology choice. (Most decision support software provides a sensitivity analysis feature.)

Decision Factors / Alternatives	Range Wt. = 2.0		Speed Wt. = 1.0		Payload Wt. = 2.5		Weighted Total
	U	W	U	W	U	W	
Transport System 1	.8	1.6	.7	.7	.6	1.5	3.8
Transport System 2	.7	1.4	.9	.9	.4	1.0	3.3
Transport System 3	.6	1.2	.7	.7	.8	2.0	3.9
Transport System 4	.5	1.0	.5	.5	.9	2.25	3.75

Key: U = Utility value
W = Weighted value

Figure 12-3. Sample Decision Matrix

CHAPTER 13

MODELING AND SIMULATION

13.1 INTRODUCTION

A model is a physical, mathematical, or logical representation of a system entity, phenomenon, or process. A simulation is the implementation of a model over time. A simulation brings a model to life and shows how a particular object or phenomenon will behave. It is useful for testing, analysis or training where real-world systems or concepts can be represented by a model.

Modeling and simulation (M&S) provides virtual duplication of products and processes, and represents those products or processes in readily available and operationally valid environments. Use of models and simulations can reduce the cost and risk of life cycle activities. As shown by Figure 13-1, the advantages are significant throughout the life cycle.

Modeling, Simulation, and Acquisition

Modeling and simulation has become a very important tool across all acquisition-cycle phases and all applications: requirements definition; program management; design and engineering;

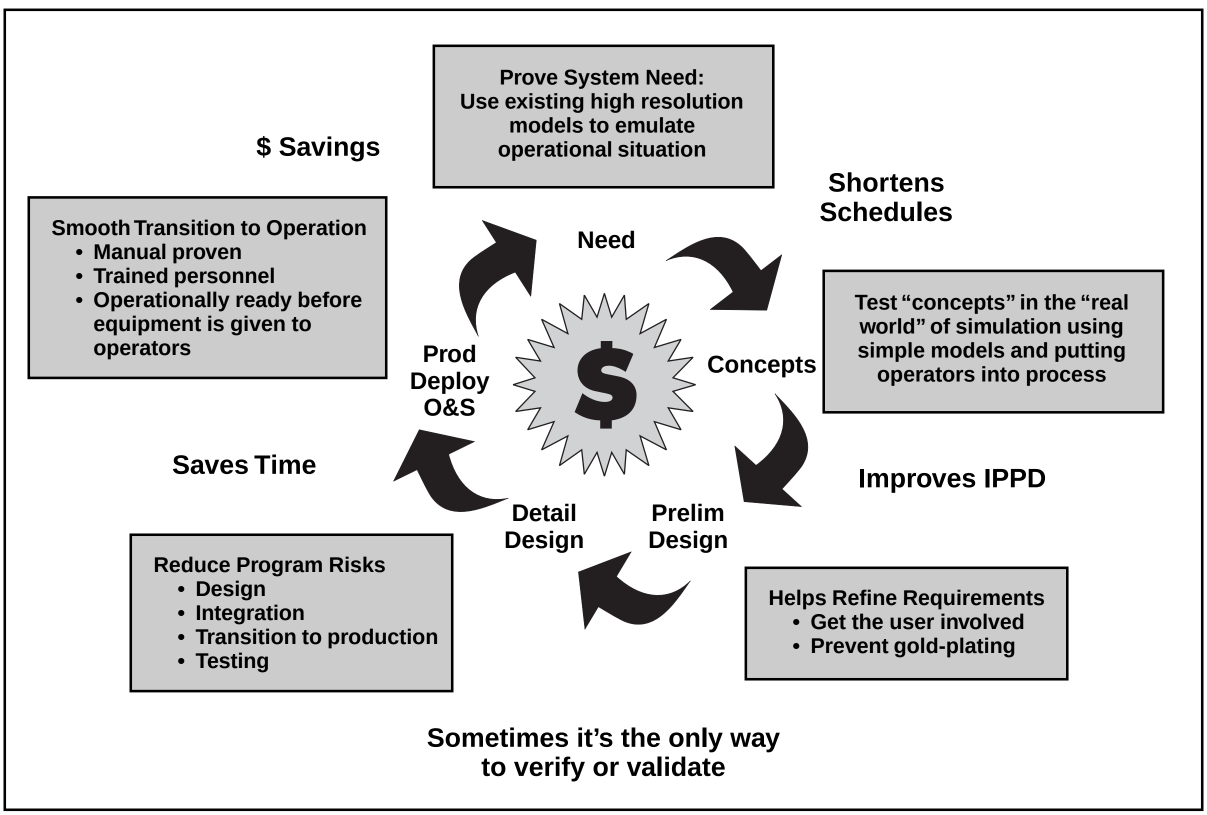

Figure 13-1. Advantages of Modeling and Simulation

efficient test planning; result prediction; supplement to actual test and evaluation; manufacturing; and logistics support. With so many opportunities to use M&S, its four major benefits; cost savings, accelerated schedule, improved product quality and cost avoidance can be achieved in any system development when appropriately applied. DoD and industry around the world have recognized these opportunities, and many are taking advantage of the increasing capabilities of computer and information technology. M&S is now capable of prototyping full systems, networks, interconnecting multiple systems and their simulators so that simulation technology is moving in every direction conceivable.

13.2 CLASSES OF SIMULATIONS

The three classes of models and simulations are virtual, constructive, and live:

- **Virtual** simulations represent systems both physically and electronically. Examples are aircraft trainers, the Navy's Battle Force Tactical Trainer, Close Combat Tactical Trainer, and built-in training.
- **Constructive** simulations represent a system and its employment. They include computer models, analytic tools, mockups, IDEF, Flow Diagrams, and Computer-Aided Design/ Manufacturing (CAD/CAM).
- **Live** simulations are simulated operations with real operators and real equipment. Examples are fire drills, operational tests, and initial production run with soft tooling.

Virtual Simulation

Virtual simulations put the human-in-the-loop. The operator's physical interface with the system is duplicated, and the simulated system is made to perform as if it were the real system. The operator is subjected to an environment that looks, feels, and behaves like the real thing. The more advanced version of this is the virtual prototype, which allows the individual to interface with a virtual mockup operating in a realistic computer-generated environment. A virtual prototype is a computer-based simulation of a system or subsystem with a degree of functional realism that is comparable to that of a physical prototype.

Constructive Simulations

The purpose of systems engineering is to develop descriptions of system solutions. Accordingly, constructive simulations are important products in all key system engineering tasks and activities. Of special interest to the systems engineer are Computer-Aided Engineering (CAE) tools. Computer-aided tools can allow more in-depth and complete analysis of system requirements early in design. They can provide improved communication because data can be disseminated rapidly to several individuals concurrently, and because design changes can be incorporated and distributed expeditiously. Key computer-aided engineering tools are CAD, CAE, CAM, Continuous Acquisition and Life Cycle Support, and Computer-Aided Systems Engineering:

Computer-Aided Design (CAD). CAD tools are used to describe the product electronically to facilitate and support design decisions. It can model diverse aspects of the system such as how components can be laid out on electrical/electronic circuit boards, how piping or conduit is routed, or how diagnostics will be performed. It is used to lay out systems or components for sizing, positioning, and space allocating using two- or three-dimensional displays. It uses three-dimensional "solid" models to ensure that assemblies, surfaces, intersections, interfaces, etc., are clearly defined. Most CAD tools automatically generate isometric and exploded views of detailed dimensional and assembly drawings, and determine component surface areas, volumes, weights, moments of inertia, centers of gravity, etc. Additionally, many CAD tools can develop three-dimensional models of facilities, operator consoles, maintenance workstations, etc., for evaluating man-machine interfaces. CAD tools are available in numerous varieties, reflecting different degrees of capabilities, fidelity, and cost. The commercial CAD/CAM product, Computer-Aided Three-Dimensional

Interactive Application (CATIA), was used to develop the Boeing 777, and is a good example of current state-of-the-art CAD.

Computer-Aided Engineering (CAE). CAE provides automation of requirements and performance analyses in support of trade studies. It normally would automate technical analyses such as stress, thermodynamic, acoustic, vibration, or heat transfer analysis. Additionally, it can provide automated processes for functional analyses such as fault isolation and testing, failure mode, and safety analyses. CAE can also provide automation of life-cycle-oriented analysis necessary to support the design. Maintainability, producibility, human factor, logistics support, and value/cost analyses are available with CAE tools.

Computer-Aided Manufacturing (CAM). CAM tools are generally designed to provide automated support to both production process planning and to the project management process. Process planning attributes of CAM include establishing Numerical Control parameters, controlling machine tools using pre-coded instructions, programming robotic machinery, handling material, and ordering replacement parts. The production management aspect of CAM provides management control over production-relevant data, uses historical actual costs to predict cost and plan activities, identifies schedule slips or slack on a daily basis, and tracks metrics relative to procurement, inventory, forecasting, scheduling, cost reporting, support, quality, maintenance, capacity, etc. A common example of a computer-based project planning and control tool is Manufacturing Resource Planning II (MRP II). Some CAM programs can accept data direct from a CAD program. With this type of tool, generally referred to as CAD/CAM, substantial CAM data is automatically generated by importing the CAD data directly into the CAM software.

Computer-Aided Systems Engineering (CASE). CASE tools provide automated support for the Systems Engineering and associated processes. CASE tools can provide automated support for integrating system engineering activities, performing the systems engineering tasks outlined in previous chapters, and performing the systems analysis and control activities. It provides technical management support and has a broader capability than either CAD or CAE. An increasing variety of CASE tools are available, as competition brings more products to market, and many of these support the commercial "best Systems Engineering practices."

Continuous Acquisition and Life Cycle Support (CALS). CALS relates to the application of computerized technology to plan and implement support functions. The emphasis is on information relating to maintenance, supply support, and associated functions. An important aspect of CALS is the importation of information developed during design and production. A key CALS function is to support the maintenance of the system configuration during the operation and support phase. In DoD, CALS supports activities of the logistics community rather than the specific program office, and transfer of data between the CAD or CAM programs to CALS has been problematic. As a result there is current emphasis on development of standards for compatible data exchange. Formats of import include: two- and three-dimensional models (CAD), ASCII formats (Technical Manuals), two-dimensional illustrations (Technical Manuals), and Engineering Drawing formats (Raster, Aperture cards). These formats will be employed in the Integrated Data Environment (IDE) that is mandated for use in DoD program offices.

Live Simulation

Live simulations are simulated operations of real systems using real people in realistic situations. The intent is to put the system, including its operators, through an operational scenario, where some conditions and environments are mimicked to provide a realistic operating situation. Examples of live simulations range from fleet exercises to fire drills.

Eventually live simulations must be performed to validate constructive and virtual simulations. However, live simulations are usually costly, and trade studies should be performed to support the balance of simulation types chosen for the program.

13.3 HARDWARE VERSUS SOFTWARE

Though current emphasis is on software M&S, the decision of whether to use hardware, software, or a combined approach is dependent on the complexity of the system, the flexibility needed for the simulation, the level of fidelity required, and the potential for reuse. Software capabilities are increasing, making software solutions cost effective for large complex projects and repeated processes. Hardware methods are particularly useful for validation of software M&S, simple or one-time projects, and quick checks on changes of production systems. M&S methods will vary widely in cost. Analysis of the cost-versus-benefits of potential M&S methods should be performed to support planning decisions.

13.4 VERIFICATION, VALIDATION, AND ACCREDITATION

How can you trust the model or simulation? Establish confidence in your model or simulation through formal verification, validation, and accreditation (VV&A). VV&A is usually identified with software, but the basic concept applies to hardware as well. Figure 13-2 shows the basic differences between the terms (VV&A).

More specifically:

- **Verification** is the process of determining that a model implementation accurately represents the developer's conceptual description and specifications that the model was designed to.

- **Validation** is the process of determining the manner and degree to which a model is an accurate representation of the real world from the perspective of the intended uses of the model, and of establishing the level of confidence that should be placed on this assessment.

- **Accreditation** is the formal certification that a model or simulation is acceptable for use for a specific purpose. Accreditation is conferred by the organization best positioned to make the judgment that the model or simulation in question is acceptable. That organization may be an operational user, the program office, or a contractor, depending upon the purposes intended.

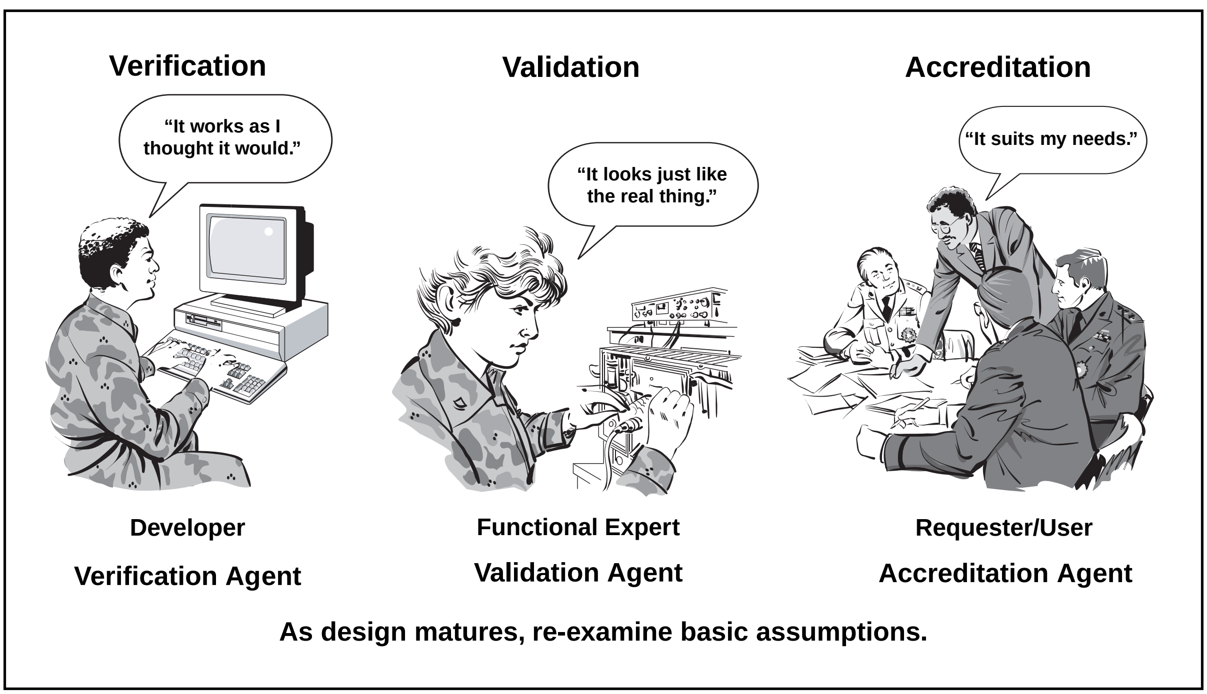

Figure 13-2. Verification, Validation, and Accreditation

VV&A is particularly necessary in cases where:

- Complex and critical interoperability is being represented,
- Reuse is intended,
- Safety of life is involved, and
- Significant resources are involved.

VV&A Currency

VV&A is applied at initial development and use. The VV&A process is required for all DoD simulations and should be redone whenever existing models and simulations undergo a major upgrade or modification. Additionally, whenever the model or simulation violates its documented methodology or inherent boundaries that were used to validate or verify by its different use, then VV&A must be redone. Accreditation, however, may remain valid for the specific application unless revoked by the Accreditation Agent, as long as its use or what it simulates doesn't change.

13.5 CONSIDERATIONS

There are a number of considerations that should enter into decisions regarding the acquisition and employment of modeling and simulation in defense acquisition management. Among these are such concerns as cost, fidelity, planning, balance, and integration.

Cost Versus Fidelity

Fidelity is the degree to which aspects of the real world are represented in M&S. It is the foundation for development of the model and subsequent VV&A. Cost effectiveness is a serious issue with simulation fidelity, because fidelity can be an aggressive cost driver. The correct balance between cost and fidelity should be the result of simulation need analysis. M&S designers and VV&A agents must decide when enough is enough. Fidelity needs can vary throughout the simulation. This variance should be identified by analysis and planned for.

Note of caution: Don't confuse the quality of the display with the quality of meeting simulation needs! An example of fidelity is a well-known flight simulator using a PC and simple joystick versus a full 6-degree of freedom fully-instrumented aircraft cockpit. Both have value at different stages of flight training, but obviously vary significantly in cost from thousands of dollars to millions. This cost difference is based on fidelity, or degree of real-world accuracy.

Planning

Planning should be an inherent part of M&S, and, therefore, it must be proactive, early, continuous, and regular. Early planning will help achieve balance and beneficial reuse and integration. With computer and simulation technologies evolving so rapidly, planning is a dynamic process. It must be a continuing process, and it is important that the appropriate simulation experts be involved to maximize the use of new capabilities. M&S activities should be a part of the integrated teaming and involve all responsible organizations. Integrated teams must develop their M&S plans and insert them into the overall planning process, including the TEMP, acquisition strategy, and any other program planning activity.

M&S planning should include:

- Identification of activities responsible for each VV&A element of each model or simulation, and
- Thorough VV&A estimates, formally agreed to by all activities involved in M&S, including T&E commitments from the developmental testers, operational testers, and separate VV&A agents.

Those responsible for the VV&A activities must be identified as a normal part of planning. Figure 13-2 shows the developer as the verification agent, the functional expert as the validation agent, and the user as the accreditation agent. In general this is appropriate for virtual simulations. However, the manufacturer of a constructive simulation would usually be expected to justify or warrantee their program's use for a particular application. The question of who should actually accomplish VV&A is one that is answered in planning. VV&A requirements should be specifically called out in tasking documents and contracts. When appropriate, VV&A should be part of the contractor's proposal, and negotiated prior to contract award.

Balance

Balance refers to the use of M&S across the phases of the product life cycle and across the spectrum of functional disciplines involved. The term may further refer to the use of hardware versus software, fidelity level, VV&A level, and even use versus non-use. Balance should always be based on cost effectiveness analysis. Cost effectiveness analyses should be comprehensive; that is, M&S should be properly considered for use in all parallel applications and across the complete life cycle of the system development and use.

Integration

Integration is obtained by designing a model or simulation to inter-operate with other models or simulations for the purpose of increased performance, cost benefit, or synergism. Multiple benefits or savings can be gained from increased synergism and use over time and across activities. Integration is achieved through reuse or upgrade of legacy programs used by the system, or of the proactive planning of integrated development of new simulations. In this case integration is accomplished through the planned utilization of models, simulations, or data for multiple times or applications over the system life cycle. The planned upgrade of M&S for evolving or parallel uses supports the application of open systems architecture to the system design. M&S efforts that are established to perform a specific function by a specific contractor, subcontractor, or government activity will tend to be sub-optimized. To achieve

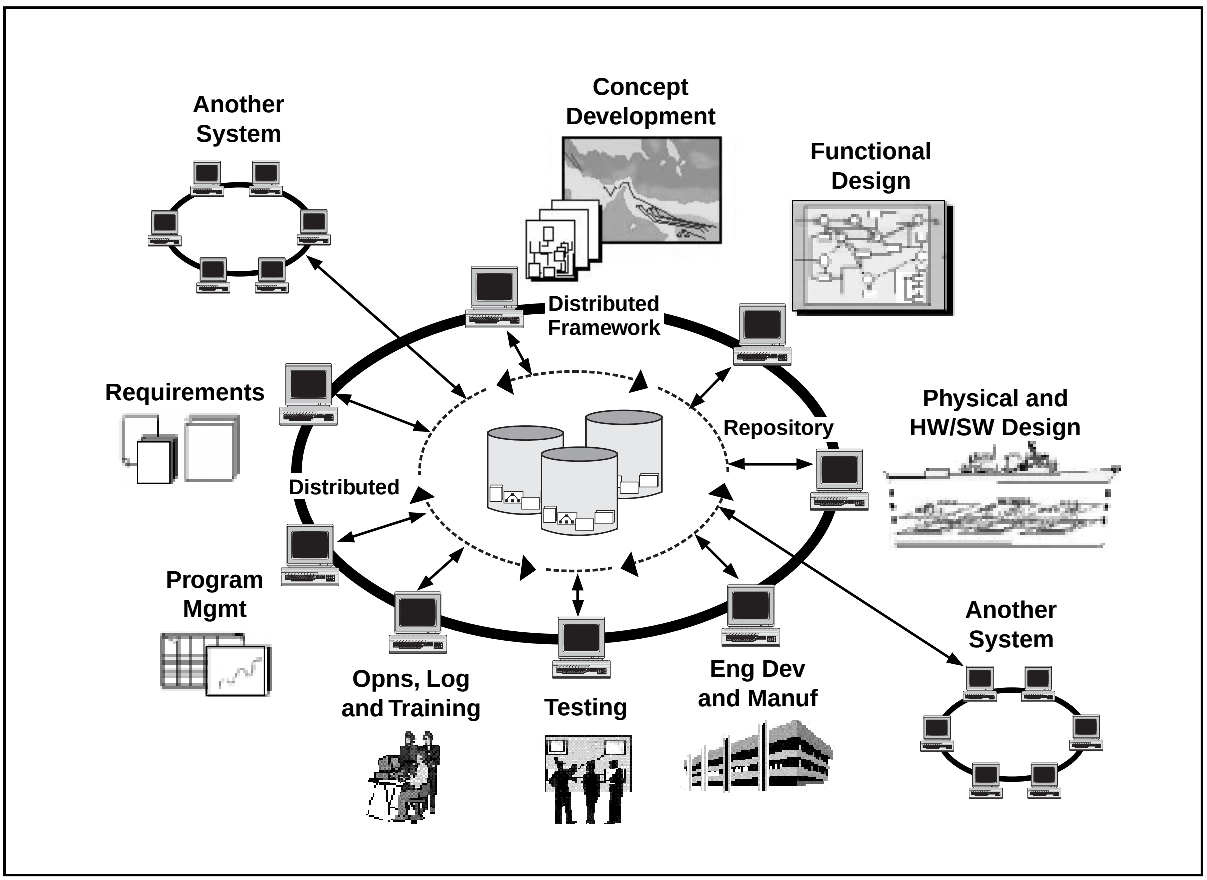

Figure 13-3. A Robust Integrated Use of Simulation Technology

integration M&S should be managed at least at the program office level.

The Future Direction

DoD, the Services, and their commands have strongly endorsed the use of M&S throughout the acquisition life cycle. The supporting simulation technology is also evolving as fast as computer technology changes, providing greater fidelity and flexibility. As more simulations are interconnected, the opportunities for further integration expand. M&S successes to date also accelerate its use. The current focus is to achieve open systems of simulations, so they can be plug-and-play across the spectrum of applications. From concept analysis through disposal analysis, programs may use hundreds of different simulations, simulators and model analysis tools. Figure 13-3 shows conceptually how an integrated program M&S would affect the functions of the acquisition process.

A formal DoD initiative, Simulation Based Acquisition (SBA), is currently underway. The SBA vision is to advance the implementation of M&S in the DoD acquisition process toward a robust, collaborative use of simulation technology that is integrated across acquisition phases and programs. The result will be programs that are much better integrated in an IPPD sense, and which are much more efficient in the use of time and dollars expended to meet the needs of operational users.

13.6 SUMMARY

- M&S provides virtual duplication of products and processes, and represent those products or processes in readily available and operationally valid environments.
- M&S should be applied throughout the system life cycle in support of systems engineering activities.
- The three classes of models and simulations are virtual, constructive, and live.
- Establish confidence in your model or simulation through formal VV&A.
- M&S planning should be an inherent part of Systems Engineering planning, and, therefore, pro-active, early, continuous, and regular.
- A more detailed discussion of the use and management of M&S in DoD acquisition is available in the DSMC publication *Systems Acquisition Manager's Guide for the Use of Models and Simulations.*
- An excellent second source is the DSMC publication, *Simulation Based Acquisition – A New Approach*. It surveys applications of increasing integration of simulation in current DoD programs and the resulting increasing benefits through greater integration.

CHAPTER 14

METRICS

14.1 METRICS IN MANAGEMENT

Metrics are measurements collected for the purpose of determining project progress and overall condition by observing the change of the measured quantity over time. Management of technical activities requires use of three basic types of metrics:

- Product metrics that track the development of the product,

- Earned Value which tracks conformance to the planned schedule and cost, and

- Management process metrics that track management activities.

Measurement, evaluation and control of metrics is accomplished through a system of periodic reporting must be planned, established, and monitored to assure metrics are properly measured, evaluated, and the resulting data disseminated.

Product Metrics

Product metrics are those that track key attributes of the design to observe progress toward meeting customer requirements. Product metrics reflect three basic types of requirements: operational performance, life-cycle suitability, and affordability. The key set of systems engineering metrics are the Technical Performance Measurements (TPM.) TPMs are product metrics that track design progress toward meeting customer performance requirements. They are closely associated with the system engineering process because they directly support traceability of operational needs to the design effort. TPMs are derived from Measures of Performance (MOPs) which reflect system requirements. MOPs are derived from Measures of Effectiveness (MOEs) which reflect operational performance requirements.

The term “metric” implies quantitatively measurable data. In design, the usefulness of metric data is greater if it can be measured at the configuration item level. For example, weight can be estimated at all levels of the WBS. Speed, though an extremely important operational parameter, cannot be allocated down through the WBS. It cannot be measured, except through analysis and simulation, until an integrated product is available. Since weight is an important factor in achieving speed objectives, and weight can be measured at various levels as the system is being developed, weight may be the better choice as a metric. It has a direct impact on speed, so it traces to the operational requirement, but, most importantly, it can be allocated throughout the WBS and progress toward achieving weight goals may then be tracked through development to production.

Measures of Effectiveness and Suitability

Measures of Effectiveness (MOEs) and Measures of Suitability (MOSs) are measures of operational effectiveness and suitability in terms of operational outcomes. They identify the most critical performance requirements to meet system-level mission objectives, and will reflect key operational needs in the operational requirements document.

Operational effectiveness is the overall degree of a system’s capability to achieve mission success considering the total operational environment. For example, weapon system effectiveness would consider environmental factors such as operator organization, doctrine, and tactics; survivability; vulnerability; and threat characteristics. MOSs, on the other hand, would measure the extent to which the system integrates well into the operation environment and would consider such issues as supportability, human interface compatibility, and maintainability.

Measures of Performance

MOPs characterize physical or functional attributes relating to the execution of the mission or function. They quantify a technical or performance requirement directly derived from MOEs and MOSs. MOPs should relate to these measures such that a change in MOP can be related to a change in MOE or MOS. MOPs should also reflect key performance requirements in the system specification. MOPs are used to derive, develop, support, and document the performance requirements that will be the basis for design activities and process development. They also identify the critical technical parameters that will be tracked through TPMs.

Technical Performance Measurements

TPMs are derived directly from MOPs, and are selected as being critical from a periodic review and control standpoint. TPMs help assess design progress, assess compliance to requirements throughout the WBS, and assist in monitoring and tracking technical risk. They can identify the need for deficiency recovery, and provide information to support cost-performance sensitivity assessments. TPMs can include range, accuracy, weight, size, availability, power output, power required, process time, and other product characteristics that relate directly to the system operational requirements.

TPMs traceable to WBS elements are preferred, so elements within the system can be monitored as well as the system as a whole. However, some necessary TPMs will be limited to the system or subsystem level. For example, the specific fuel consumption of an engine would be a TPM necessary to track during the engine development, but it is not allocated throughout the WBS. It is reported as a single data item reflecting the performance of the engine as a whole. In this case the metric will indicate that the design approach is consistent with the required performance, but it may not be useful as an early warning device to indicate progress toward meeting the design goal. A more detailed discussion of TPMs is available as Supplement A to this chapter.

Example of Measures

MOE: The vehicle must be able to drive fully loaded from Washington, DC, to Tampa on one tank of fuel.

MOP: Vehicle range must be equal to or greater than 1,000 miles.

TPM: Fuel consumption, vehicle weight, tank size, drag, power train friction, etc.

Suitability Metrics

Tracking metrics relating to operational suitability and other life cycle concerns may be appropriate to monitor progress toward an integrated design. Operational suitability is the degree to which a system can be placed satisfactorily in field use considering availability, compatibility, transportability, interoperability, reliability, usage rates, maintainability, safety, human factors, documentation, training, manpower, supportability, logistics, and environmental impacts. These suitability parameters can generate product metrics that indicate progress toward an operationally suitable system. For example, factors that indicate the level of automation in the design would reflect progress toward achieving manpower quantity and quality requirements. TPMs and suitability product metrics commonly overlap. For example, Mean Time Between Failure (MBTF) can reflect both effectiveness or suitability requirements.

Suitability metrics would also include measurements that indicate improvement in the producibility, testability, degree of design simplicity, and design robustness. For example, tracking number of parts, number of like parts, and number of wearing parts provides indicators of producibility, maintainability, and design simplicity.

Product Affordability Metrics

Estimated unit production cost can be tracked during the design effort in a manner similar to the TPM approach, with each CI element reporting an estimate based on current design. These estimates are combined at higher WBS levels to provide subsystem and system cost estimates. This provides a running engineering estimate of unit production cost, tracking of conformance to Design-to-Cost (DTC) goals, and a method to isolate design problems relating to production costs.

Life cycle affordability can be tracked through factors that are significant in parametric life cycle cost calculations for the particular system. For example, two factors that reflect life cycle cost for most transport systems are fuel consumption and weight, both of which can be tracked as metrics.

Timing

Product metrics are tied directly to the design process. Planning for metric identification, reporting, and analysis is begun with initial planning in the concept exploration phase. The earliest systems engineering planning should define the management approach, identify performance or characteristics to be measured and tracked, forecast values for those performances or characteristics, determine when assessments will be done, and establish the objectives of assessment.

Implementation is begun with the development of the functional baseline. During this period, systems engineering planning will identify critical technical parameters, time phase planned profiles with tolerance bands and thresholds, reviews or audits or events dependent or critical for achievement of planned profiles, and the method of estimation. During the design effort, from functional to product baseline, the plan will be implemented and continually updated by the systems engineering process. To support implementation, contracts should include provision for contractors to provide measurement, analysis, and reporting. The need to track product metrics ends in the production phase, usually concurrent with the establishment of the product (as built) baseline.

DoD and Industry Policy on Product Metrics

Analysis and control activities shall include performance metrics to measure technical development and design, actual versus planned; and to measure [the extent to which systems meet requirements]. DoD 5000.2-R.

The performing activity establishes and implements TPM to evaluate the adequacy of evolving solutions to identify deficiencies impacting the ability of the system to satisfy a designated value for a technical parameter. EIA IS-632, Section 3.

The performing activity identifies the technical performance measures which are key indicators of system performance...should be limited to critical MOPs which, if not met put the project at cost, schedule, or performance risk. IEEE 1220, Section 6.

14.2 EARNED VALUE

Earned Value is a metric reporting system that uses cost-performance metrics to track the cost and schedule progress of system development against a projected baseline. It is a "big picture" approach and integrates concerns related to performance, cost, and schedule. Referring to Figure 14-1, if we think of the line labeled BCWP (budgeted cost of work performed) as the value that the contractor has "earned," then deviations from this baseline indicate problems in either cost or schedule. For example, if actual costs vary from budgeted costs, we have a cost variance; if work performed varies from work planned, we have a schedule variance. The projected performance is based on estimates of appropriate cost and schedule to perform the work required by each WBS element. When a variance occurs the system engineer can pinpoint WBS elements that have potential technical development problems. Combined with product metrics, earned value is a powerful technical management tool for detecting and understanding development problems.

Relationships exist between product metrics, the event schedule, the calendar schedule, and Earned

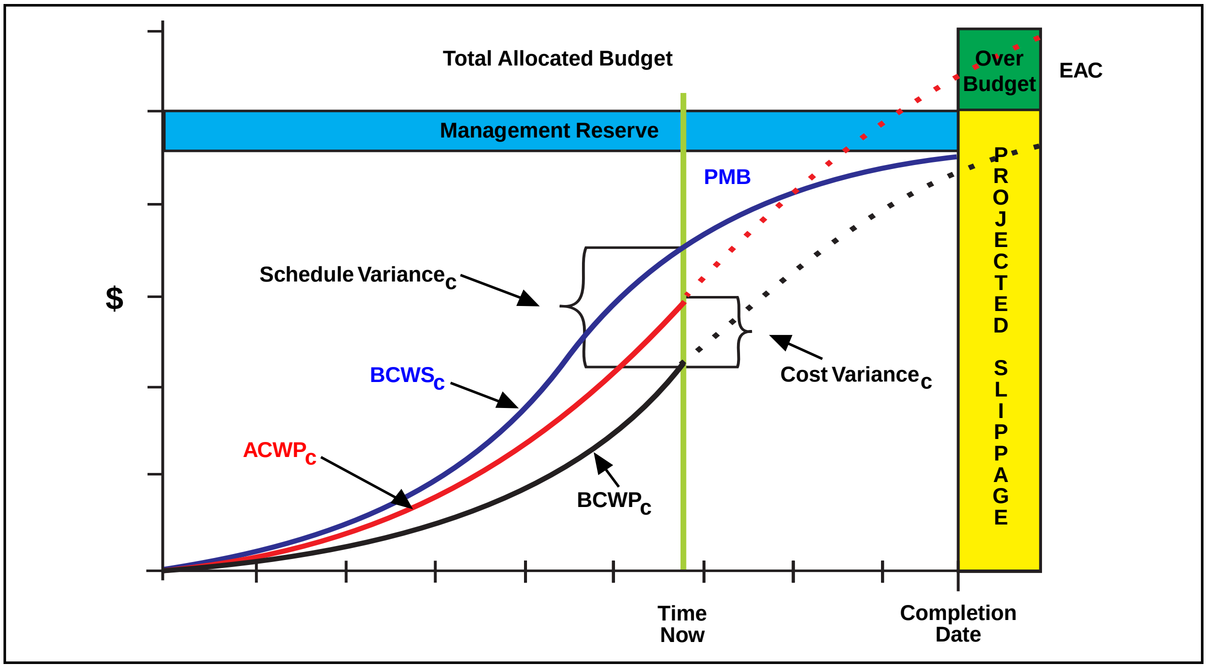

Figure 14-1. Earned Value Concept

Value:

- The Event Schedule includes tasks for each event/exit criteria that must be performed to meet key system requirements, which are directly related to product metrics.
- The Calendar (Detail) Schedule includes time frames established to meet those same product metric-related objectives (schedules).
- Earned Value includes cost/schedule impacts of not meeting those objectives, and, when correlated with product metrics, can identify emerging program and technical risk.

14.3 PROCESS METRICS

Management process metrics are measurements taken to track the process of developing, building, and introducing the system. They include a wide range of potential factors and selection is program unique. They measure such factors as availability of resources, activity time rates, items completed, completion rates, and customer or team satisfaction.

Examples of these factors are: number of trained personnel onboard, average time to approve/disapprove ECPs, lines of code or drawings released, ECPs resolved per month, and team risk identification or feedback assessments. Selection of appropriate metrics should be done to track key management activities. Selection of these metrics is part of the systems engineering planning process.

How Much Metrics?

The choice of the amount and depth of metrics is a planning function that seeks a balance between risk and cost. It depends on many considerations, including system complexity, organizational complexity, reporting frequency, how many contractors, program office size and make up, contractor past performance, political visibility, and contract type.

14.4 SUMMARY POINTS

- Management of technical activities requires use of three basic types of metrics: product metrics that track the development of the product, earned value which tracks conformance to the planned schedule and cost, and management process metrics that track management activities.

- Measurement, evaluation and control of metrics is accomplished through a system of periodic reporting that must be planned, established, and monitored to assure metrics are measured properly, evaluated, and the resulting data disseminated.

- TPMs are performance based product metrics that track progress through measurement of key technical parameters. They are important to the systems engineering process because they connect operational requirements to measurable design characteristics and help assess how well the effort is meeting those requirements. TPMs are required for all programs covered by DoD 5000.2-R.

SUPPLEMENT 14-A

TECHNICAL PERFORMANCE MEASUREMENT

Technical Performance Measurement (TPM) is an analysis and control technique that is used to: (1) project the probable performance of a selected technical parameter over a period of time, (2) record the actual performance observed of the selected parameter, and (3) through comparison of actual versus projected performance, assist the manager in decision making. A well thought out program of technical performance measures provides an early warning of technical problems and supports assessments of the extent to which operational requirements will be met, as well as assessments of the impacts of proposed changes in system performance.

TPMs generally take the form of both graphic displays and narrative explanations. The graphic, an example of which is shown in Figure 14-2, shows the projected behavior of the selected parameter as a function of time, and further shows actual observations, so that deviations from the planned profile can be assessed. The narrative portion of the report should explain the graphic, addressing the reasons for deviations from the planned profile, assessing the seriousness of those deviations, explaining actions underway to correct the situation if required, and projecting future performance, given the current situation.

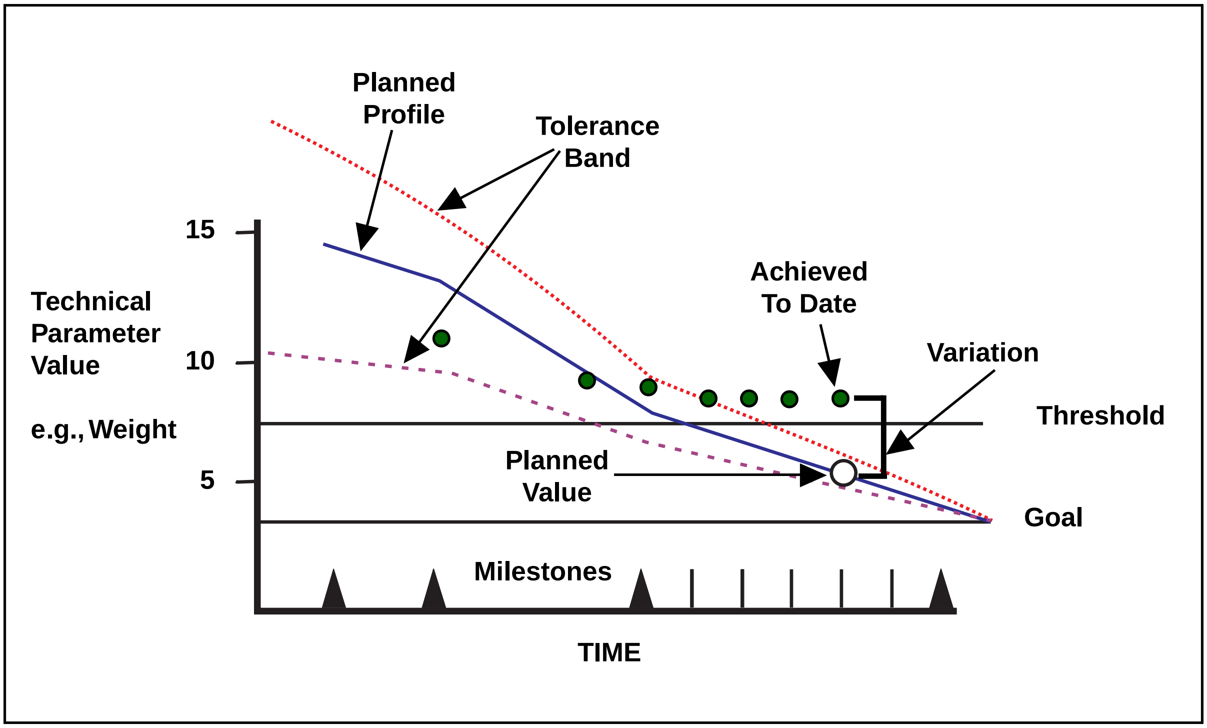

Figure 14-2. Technical Performance Measurement – The Concept

Parameters to be tracked are typically based on the combined needs of the government and the contractor. The government program office will need a set of TPMs which provide visibility into the technical performance of key elements of the WBS, especially those which are cost drivers on the program, lie on the critical path, or which represent high risk items.

The TPMs selected for delivery to the government are expected to be traceable to the needs of the operational user. The contractor will generally track more items than are reported to the government, as the contractor needs information at a more detailed level than does the government program office.

TPM reporting to the government is a contractual issue, and those TPMs on which the government receives reports are defined as contract deliverables in the contract data requirements list. Which parameters are selected for reporting depends on a number of issues, among which are resources to purchase TPMs, the availability of people to review and follow the items, the complexity of the system involved, the phase of development, and the contractor's past experience with similar systems.

A typical TPM graphic will take a form somewhat like that previously shown. The actual form of the projected performance profile and whether or not tolerance bands are employed will be a function of the parameter selected and the needs of the program office.

Another important consideration is the relationship between the TPM program and risk management. Generally, the parameters selected for tracking should be related to the risk areas on the program. If a particular element of the design has been identified as a risk area, then parameters should be selected which will enable the manager to track progress in that area. For example, if achieving a required aircraft range is considered to be critical and a risk area, then tracking parameters that provide insight into range would be selected, such as aircraft weight, specific fuel consumption, drag, etc. Furthermore, there should be consistency between TPMs and the Critical Technical Parameters associated with formal testing, although the TPM program will not normally be limited just to those parameters identified as critical for test purposes.

Government review and follow up of TPMs are appropriate on a periodic basis when submitted by the contractor, and at other major technical events such as at technical reviews, test events, and program management reviews.

While TPMs are expected to be traceable to the needs of the user, they must be concrete technical parameters that can be projected and tracked. For example, an operational user may have a requirement for survivability under combat conditions. Survivability is not, in and of itself, a measurable parameter, but there are important technical parameters that determine survivability, such as radar cross section (RCS) and speed. Therefore, the technical manager might select and track RCS and speed as elements for TPM reporting. The decision on selection of parameters for TPM tracking must also take into consideration the extent to which the parameter behavior can be projected (profiled over a time period) and whether or not it can actually be measured. If the parameter cannot be profiled, measured, or is not critical to program success, then the government, in general, should not select it for TPM tracking. The WBS structure makes an excellent starting point for consideration of parameters for TPM tracking (see Figure 14-3).

A substantial effort has taken place in recent years to link TPMs with Earned Value Management in a way that would result in earned value calculations that reflect the risks associated with achieving technical performance. The approach used establishes statistical probability of achieving a projected level of performance on the TPM profile based on a statistical analysis of actual versus planned performance.

In summary, TPMs are an important tool in the program manager's systems analysis and control toolkit. They provide an early warning about deviations in key technical parameters, which, if not controlled, can impact system success in meeting user needs. TPMs should be an integral part of both

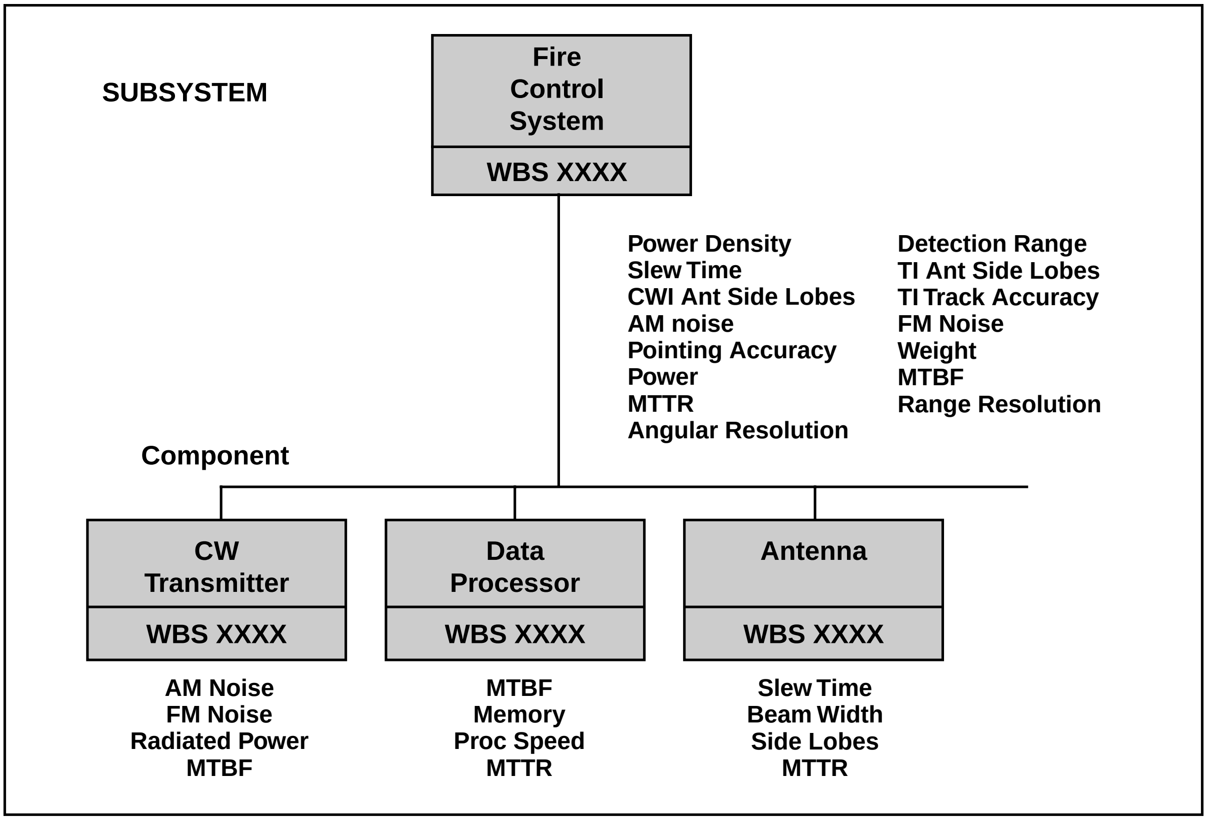

Figure 14-3. Shipboard Fire Control System (Partial)

periodic program reporting and management follow-up, as well as elements for discussion in technical reviews and program management reviews. By thoughtful use of a good program of TPM, the manager, whether technically grounded or not, can make perceptive judgments about system technical performance and can follow up on contractor plans and progress when deviations occur.

Relevant Terms

Achievement to date – Measured or estimated progress plotted and compared with planned progress by designated milestone date.

Current estimate – Expected value of a technical parameter at contract completion.

Planned value – Predicted value of parameter at a given point in time.

Planned profile – Time phased projected planned values.

Tolerance band – Management alert limits representing projected level of estimating error.

Threshold – Limiting acceptable value, usually contractual.

Variance – Difference between the planned value and the achievement-to-date derived from analysis, test, or demonstration.

CHAPTER 15

RISK MANAGEMENT

15.1 RISK AS REALITY

Risk is inherent in all activities. It is a normal condition of existence. Risk is the potential for a negative future reality that may or may not happen. Risk is defined by two characteristics of a possible negative future event: probability of occurrence (whether something will happen), and consequences of occurrence (how catastrophic if it happens). If the probability of occurrence is not known then one has *uncertainty*, and the risk is undefined.

Risk is not a problem. It is an understanding of the level of threat due to *potential* problems. A problem is a consequence that has already occurred.

In fact, knowledge of a risk is an opportunity to avoid a problem. Risk occurs whether there is an attempt to manage it or not. Risk exists whether you acknowledge it, whether you believe it, whether if it is written down, or whether you understand it. Risk does not change because you hope it will, you ignore it, or your boss's expectations do not reflect it. Nor will it change just because it is contrary to policy, procedure, or regulation. Risk is neither good nor bad. It is just how things are. Progress and opportunity are companions of risk. In order to make progress, risks must be understood, managed, and reduced to acceptable levels.

Types of Risk in a
Systems Engineering Environment

Systems engineering management related risks could be related to the system products or to the process of developing the system. Figure 15-1 shows the decomposition of system development risks.

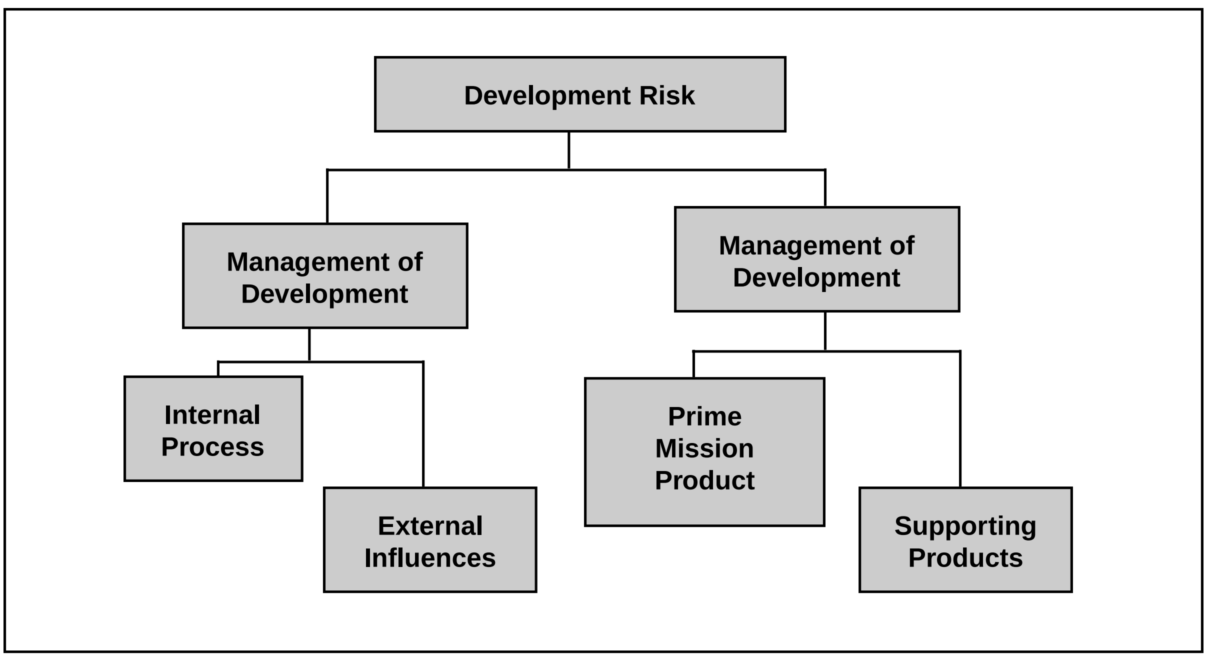

Figure 15-1. Risk Hierarchy

Risks related to the system development generally are traceable to achieving life cycle customer requirements. Product risks include both end product risks that relate to the basic performance and cost of the system, and to enabling products that relate to the products that produce, maintain, support, test, train, and dispose of the system.

Risks relating to the management of the development effort can be technical management risk or risk caused by external influences. Risks dealing with the internal technical management include those associated with schedules, resources, work flow, on time deliverables, availability of appropriate personnel, potential bottlenecks, critical path operations and the like. Risks dealing with external influences include resource availability, higher authority delegation, level of program visibility, regulatory requirements, and the like.

15.2 RISK MANAGEMENT

Risk management is an organized method for identifying and measuring risk and for selecting, developing, and implementing options for the handling of risk. It is a process, not a series of events. Risk management depends on risk management planning, early identification and analysis of risks, continuous risk tracking and reassessment, early implementation of corrective actions, communication, documentation, and coordination. Though there are many ways to structure risk management, this book will structure it as having four parts: Planning, Assessment, Handling, and Monitoring. As depicted in Figure 15-2 all of the parts are interlocked to demonstrate that after initial planning the parts begin to be dependent on each other. Illustrating this, Figure 15-3 shows the key control and feedback relationships in the process.

Risk Planning

Risk Planning is the continuing process of developing an organized, comprehensive approach to risk management. The initial planning includes establishing a strategy; establishing goals and objectives; planning assessment, handling, and monitoring activities; identifying resources, tasks, and responsibilities; organizing and training risk management IPT members; establishing a method to track risk items; and establishing a method to

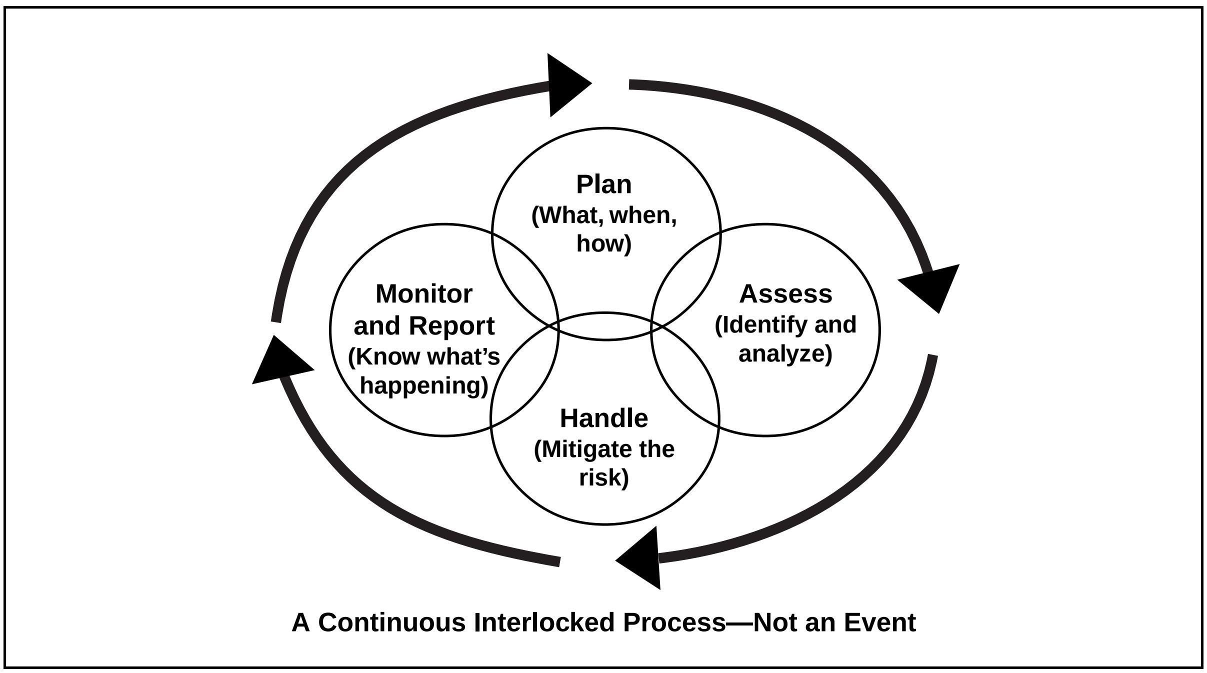

Figure 15-2. Four Elements of Risk Management

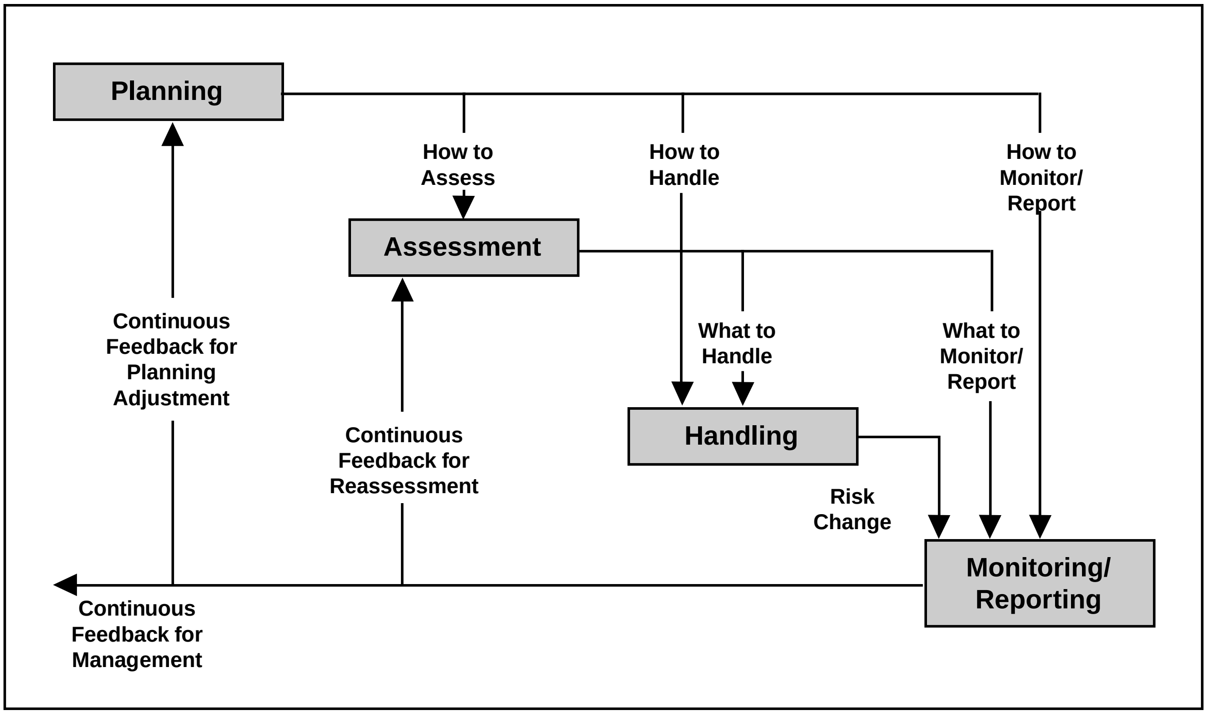

Figure 15-3. Risk Management Control and Feedback

document and disseminate information on a continuous basis.

In a systems engineering environment risk planning should be:

- Inherent (imbedded) in systems engineering planning and other related planning, such as producibility, supportability, and configuration management;
- A documented, continuous effort;
- Integrated among all activities;
- Integrated with other planning, such as systems engineering planning, supportability analysis, production planning, configuration and data management, etc.;
- Integrated with previous and future phases; and
- Selective for each Configuration Baseline.

Risk is altered by time. As we try to control or alter risk, its probability and/or consequence will change. Judgment of the risk impact and the method of handling the risk must be reassessed and potentially altered as events unfold. Since these events are continually changing, the planning process is a continuous one.

Risk Assessment

Risk assessment consists of *identifying* and *analyzing* the risks associated with the life cycle of the system.

Risk Identification Activities

Risk identification activities establish what risks are of concern. These activities include:

- Identifying risk/uncertainty sources and drivers,
- Transforming uncertainty into risk,
- Quantifying risk,
- Establishing probability, and
- Establishing the priority of risk items.

As shown by Figure 15-4 the initial identification process starts with an identification of potential risk items in each of the four risk areas. Risks related to the system performance and supporting products are generally organized by WBS and initially determined by expert assessment of teams and individuals in the development enterprise. These risks tend to be those that require follow-up quantitative assessment. Internal process and external influence risks are also determined by expert assessment within the enterprise, as well as through the use of risk area templates similar to those found in DoD 4245.7-M. The DoD 4245.7-M templates describe the risk areas associated with system acquisition management processes, and provide methods for reducing traditional risks in each area. These templates should be tailored for specific program use based on expert feedback.

After identifying the risk items, the risk level should be established. One common method is through the use of a matrix such as shown in Figure 15-5. Each item is associated with a block in the matrix to establish relative risk among them. On such a graph risk increases on the diagonal and provides a method for assessing relative risk. Once the relative risk is known, a priority list can be established and risk analysis can begin.

Risk identification efforts can also include activities that help define the probability or consequences of a risk item, such as:

- Testing and analyzing uncertainty away,
- Testing to understand probability and consequences, and
- Activities that quantify risk where the qualitative nature of high, moderate, low estimates are insufficient for adequate understanding.

Risk Analysis Activities

Risk analysis activities continue the assessment process by refining the description of identified risk event through isolation of the cause of risk, determination of the full impact of risk, and the

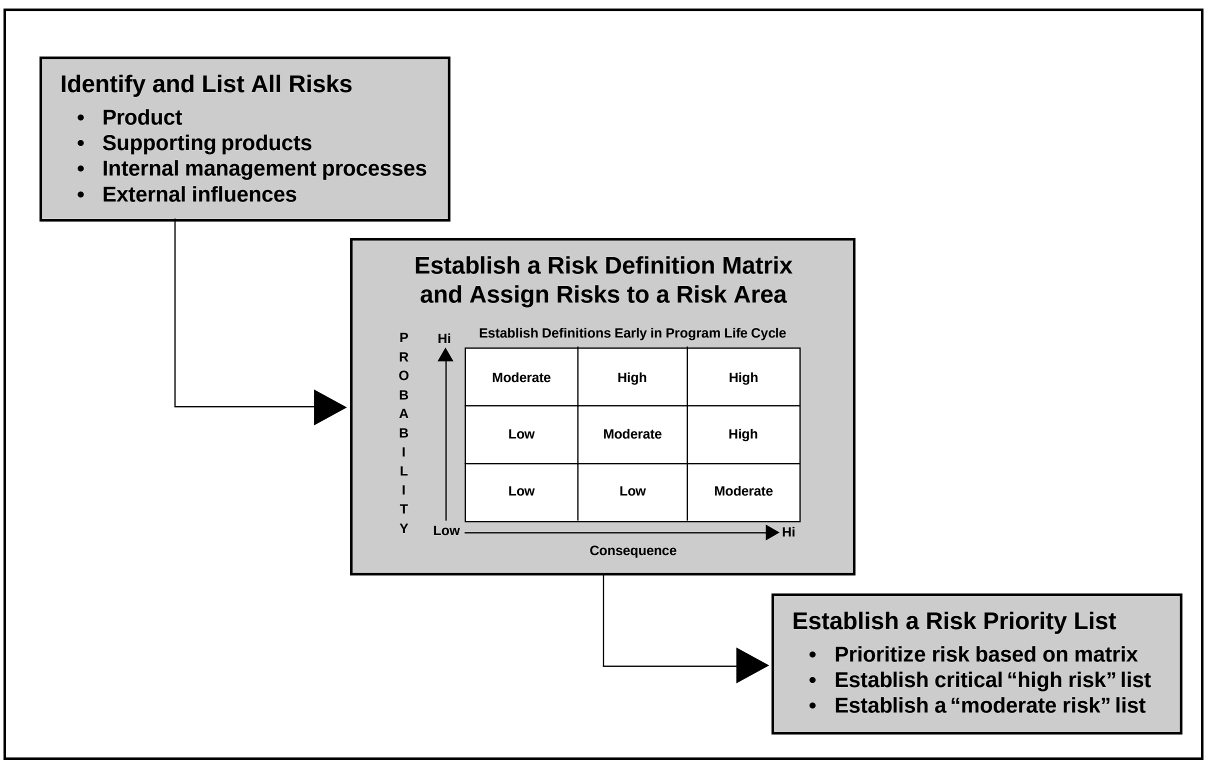

Figure 15-4. Initial Risk Identificaiton

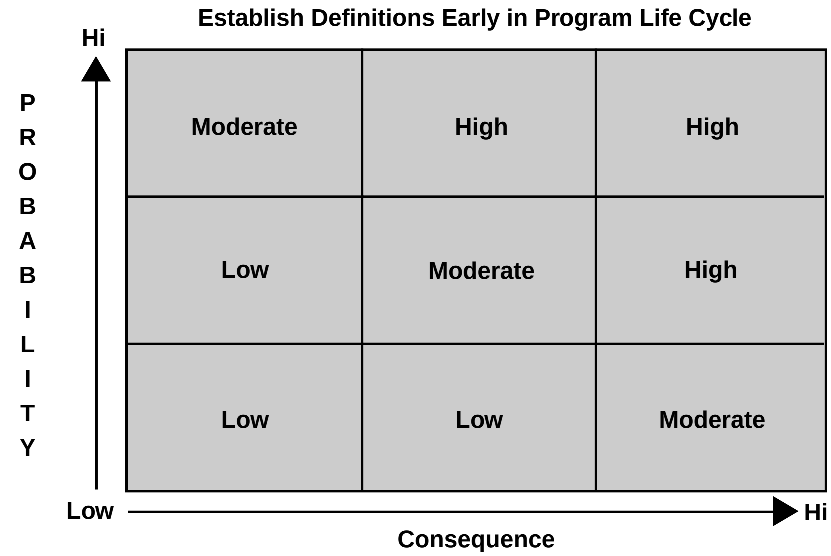

Figure 15-5. Simple Risk Matrix

determination and choose of alternative courses of action. They are used to determine what risk should be tracked, what data is used to track risk, and what methods are used to handle the risk.

Risk analysis explores the options, opportunities, and alternatives associated with the risk. It addresses the questions of how many legitimate ways the risk could be dealt with and the best way to do so. It examines sensitivity, and risk interrelationships by analyzing impacts and sensitivity of related risks and performance variation. It further analyzes the impact of potential and accomplished, external and internal changes.

Risk analysis activities that help define the scope and sensitivity of the risk item include finding answers to the following questions:

- If something changes, will risk change faster, slower, or at the same pace?
- If a given risk item occurs, what collateral effects happen?
- How does it affect other risks?
- How does it affect the overall situation?
- Development of a watch list (prioritized list of risk items that demand constant attention by management) and a set of metrics to determine if risks are steady, increasing, or decreasing.
- Development of a feedback system to track metrics and other risk management data.
- Development of quantified risk assessment.

Quantified risk assessment is a formal quantification of probabilities of occurrence and consequences using a top-down structured process following the WBS. For each element, risks are assessed through analysis, simulation and test to determine statistical probability and specific conditions caused by the occurrence of the consequence.

Cautions in Risk Assessments

Reliance solely on numerical values from simulations and analysis should be avoided. Do not lose sight of the actual source and consequences of the risks. Testing does not eliminate risk. It only provides data to assess and analyze risk. Most of all, beware of manipulating relative numbers, such as ‘risk index” or “risk scales,” even when based on expert opinion, as quantified data. They are important information, but they are largely subjective and relative; they do not necessarily define risk accurately. Numbers such as these should always be the subject of a sensitivity analysis.

Risk Handling

Once the risks have been categorized and analyzed, the process of handling those risks is initiated. The prime purpose of risk handling activities is to mitigate risk. Methods for doing this are numerous, but all fall into four basic categories:

- Risk Avoidance,
- Risk Control,
- Risk Assumption, and
- Risk Transfer.

Avoidance

To avoid risk, remove requirements that represent uncertainty and high risk (probability or consequence.) Avoidance includes trading off risk for performance or other capability, and it is a key activity during requirements analysis. Avoidance requires understanding of priorities in requirements and constraints. Are they mission critical, mission enhancing, nice to have, or “bells and whistles?”

Control

Control is the deliberate use of the design process to lower the risk to acceptable levels. It requires the disciplined application of the systems engineering process and detailed knowledge of the technical area associated with the design. Control techniques are plentiful and include:

- Multiple concurrent design to provide more than one design path to a solution,
- Alternative low-risk design to minimize the risk of a design solution by using the lowest-risk design option,
- Incremental development, such as preplanned product improvement, to dissociate the design from high-risk components that can be developed separately,
- Technology maturation that allows high-risk components to be developed separately while the basic development uses a less risky and lower-performance temporary substitute,
- Test, analyze and fix that allows understanding to lead to lower risk design changes. (Test can be replaced by demonstration, inspection, early prototyping, reviews, metric tracking, experimentation, models and mock-ups, simulation, or any other input or set of inputs that gives a better understanding of the risk),
- Robust design that produces a design with substantial margin such that risk is reduced, and
- The open system approach that emphasizes use of generally accepted interface standards that provide proven solutions to component design problems.

Acceptance

Acceptance is the deliberate acceptance of the risk because it is low enough in probability and/or consequence to be reasonably assumed without impacting the development effort. Key techniques for handling accepted risk are budget and schedule reserves for unplanned activities and continuous assessment (to assure accepted risks are maintained at acceptance level). The basic objective of risk management in systems engineering is to reduce all risk to an acceptable level.

The strong budgetary strain and tight schedules on DoD programs tends to reduce the program manager’s and system engineer’s capability to provide reserve. By identifying a risk as acceptable, the worst-case outcome is being declared acceptable. Accordingly, the level of risk considered acceptable should be chosen very carefully in a DoD acquisition program.

Transfer

Transfer can be used to reduce risk by moving the risk from one area of design to another where a design solution is less risky. Examples of this include:

- Assignment to hardware (versus software) or vice versa; and

- Use of functional partitioning to allocate performance based on risk factors.

Transfer is most associated with the act of assigning, delegating, or paying someone to assume the risk. To some extent transfer always occurs when contracting or tasking another activity. The contract or tasking document sets up agreements that can transfer risk from the government to contractor, program office to agency, and vice versa. Typical methods include insurance, warranties, and incentive clauses. Risk is never truly transferred. If the risk isn't mitigated by the delegated activity it still affects your project or program.

Key areas to review before using transfer are:

- How well can the delegated activity handle the risk? Transfer is effective only to the level the risk taker can handle it.

- How well will the delegated activity solution integrate into your project or program? Transfer is effective only if the method is integrated with the overall effort. For example, is the warranty action coordinated with operators and maintainers?

- Was the method of tasking the delegated activity proper? Transfer is effective only if the transfer mechanism is valid. For example, can incentives be "gamed?"

- Who has the most control over the risk? If the project or program has no or little control over the risk item, then transfer should be considered to delegate the risk to those most likely to be able to control it.

Monitoring and Reporting

Risk monitoring is the continuous process of tracking and evaluating the risk management process by metric reporting, enterprise feedback on watch list items, and regular enterprise input on potential developing risks. (The metrics, watch lists, and feedback system are developed and maintained as an assessment activity.) The output of this process is then distributed throughout the enterprise, so that all those involved with the program are aware of the risks that affect their efforts and the system development as a whole.

Special Case – Integration as Risk

Integration of technologies in a complex system is a technology in itself! Technology integration during design may be a high-risk item. It is not normally assessed or analyzed as a separately identified risk item. If integration risks are not properly identified during development of the functional baseline, they will demonstrate themselves as serious problems in the development of the product baseline.

Special Case – Software Risk

Based on past history, software development is often a high-risk area. Among the causes of performance, schedule, and cost deficiencies have been:

- Imperfect understanding of operational requirements and its translation into source instructions,

- Risk tracking and handling,

- Insufficient comprehension of interface constraints, and

- Lack of sufficient qualified personnel.

Risk Awareness

All members of the enterprise developing the system must understand the need to pay attention to the existence and changing nature of risk.

Consequences that are unanticipated can seriously disrupt a development effort. The uneasy feeling that something is wrong, despite assurances that all is fine may be valid. These kinds of intuitions have allowed humanity to survive the slings and arrows of outrageous fortune throughout history. Though generally viewed as non-analytical, these apprehensions should not be ignored. Experience indicates those non-specific warnings have validity, and should be quantified as soon as possible.

15.3 SUMMARY POINTS

- Risk is inherent in all activities.
- Risk is composed of knowledge of two characteristics of a possible negative future event: probability of occurrence and consequences of occurrence.
- Risk management is associated with a clear understanding of probability.
- Risk management is an essential and integral part of technical program management (systems engineering).
- Risks and uncertainties must be identified, analyzed, handled, and tracked.
- There are four basic ways of handling risk: avoidance, transfer, acceptance, and control.
- Program risks are classified as low, moderate, or high depending on consequences and probability of occurrence. Risk classification should be based on quantified data to the extent possible.

SUPPLEMENT 15-A

RISK MANAGEMENT IN DOD ACQUISITION

Policy

DoD policy is quite clear in regard to risk management: it must be done.

The PM shall identify the risk areas in the program and integrate risk management within overall program management. (DoD 5000.2-R.)

In addition, DoDD 5000.4 identifies risk and cost analysis as a responsibility of the program manager.

Risk Management View

A DSMC study indicates that major programs which declared moderate risk at Milestone B have been more successful in terms of meeting cost and schedule goals than those which declared low risk (DSMC TR 2-95). This strongly implies that program offices that understand and respect risk management will be more successful. For this reason, the program office needs to adopt a systems-level view of risk. The systems engineer provides this view. Systems Engineering is the cornerstone of program office risk management program because it is the connection to realistic assessment of product maturity and development, and the product is, in the final analysis, what system acquisition is really about.

However, the program office has external risks to deal with as well as the internal risks prevalent in the development process. The Systems Engineer has to provide the program manager internal risk data in a manner that aids the handling of the external risks. In short, the systems engineer must present bad news such that it is reasonable and compelling to higher levels of authority. See Chapter 20 for further discussion on this topic.

Factoring Risk Management into the Process

Risk management, as an integral part of the overall program planning and management process, is enhanced by applying a controlled, consistent, approach to systems engineering and using integrated teams for both product development and management control. Programs should be transitioned to the next phase only if risk is at the appropriate level. Know the risk drivers behind the estimates. By its nature there are always subjective aspects to assessing and analyzing risk at the system level, even though they tend to be represented as quantitative and/or analytically objective.

Risk and Phases

Risk management begins in the Concept and Technology Development phase. During Concept Exploration initial system level risk assessments are made. Unknown-unknowns, uncertainty, and some high-risk elements are normal and expected. When substantial technical risk exists, the Component Advanced Development stage is appropriate, and is included in the life-cycle process specifically as an opportunity to address and reduce risks to a level that are consistent with movement into systems acquisition.

The S&T community has a number of vehicles available that are appropriate for examining technology in application and for undertaking risk reduction activities. These include Advanced Technology Demonstrations, Advanced Concept Technology Demonstrations, as well as Joint Warfighting Experiments. The focus of the activities undertaken during these risk reduction stages include:

- Testing, analyzing, or mitigating system and subsystem uncertainty and high risk out of the program.
- Demonstrating technology sufficient to uncover system and subsystem unknown-unknowns (especially for integration).
- Planning for risk management during the transition to and continuation of systems acquisition during the System Development and Demonstration phase, especially handling and tracking of moderate risk.

System Development and Demonstration requires the application of product and manufacturing engineering, which can be disrupted if the technology development is not sufficient to support engineering development. Risk management in during this phase emphasizes:

- Reduction and control of moderate risks,
- All risks under management including emerging ones, and
- Maintenance of risk levels and reaction to problems.

Objective Assessment of Technology

The revised acquisition process has been deliberately structured to encourage and allow programs to progress through appropriate risk reduction stages and phases, based on an objective assessment of the maturity levels associated with the products and systems under development. It is therefore, particularly important that program managers and their staffs ensure that the decisions made regarding recommendations to proceed, and the paths to be taken, be based on as impartial and objective opinions as possible. The temptation is always to move ahead and not to delay to improve the robustness of a given product or system. When systems are hurried into engineering development and production, in spite of the fact that the underlying technologies require further development, history indicates that the results will eventually show the fallacy of speed over common sense. And to fix the problem in later stages of development—or even after deployment—can be hugely expensive in terms of both monetary cost and human lives.

The prevailing presumption at Milestone B is that the system is ready for engineering development. After this, the acquisition community generally assumes that risk is moderate to low, that the technology is "available." There is evidence to support the assertion that programs often progress into engineering development with risks that actually require substantial exploratory and applied research and development to bring them to the moderate levels of risk or lower. One approach that has proven successful in making objective risk assessments is the use of independent evaluation teams. Groups that have no pre-determined interest to protect or axe to grind are often capable of providing excellent advice regarding the extent to which a system is ready to proceed to the next level of development and subsequent phases.

Risk Classification on the System (Program) Level

Classification definitions should be established early and remain consistent throughout the program. The program office should assess the risks of achieving performance, schedule, and cost in clear and accurate terms of both probability and consequence. Where there is disagreement about the risk, assessment efforts should be immediately increased. Confusion over risk is the worst program risk, because it puts in doubt the validity of the risk management process, and therefore, whether program reality is truly understood.

The system level risk assessment requires integration and interpretation of the quantified risk assessment of the parts. This requires reasonable judgement. Because integration increases the potential for risk, it is reasonable to assume overall risk is not better than the sum of objective data for the parts.

Reality Versus Expectations

Program managers are burdened with the expectations of superiors and others that have control over the program office's environment. Pressure to accommodate these expectations is high. If the systems engineer cannot communicate the reality of risk in terms that are understandable, acceptable, or sufficiently verifiable to management, then these pressures may override vertical communication of actual risk.

Formal systems engineering with risk management incorporated can provide the verifiable information. However, the systems engineer also has the responsibility to adequately explain probability and consequences such that the program manager can accept the reality of the risk and override higher level expectations.

Uncertainty is a special case, and very dangerous in an atmosphere of high level expectations. Presentation of uncertainty issues should strongly emphasize consequences, show probability trends, and develop "most likely" alternatives for probability.

SUPPLEMENT 15-B

MODEL FOR SYSTEM LEVEL RISK ASSESSMENT

The following may be used to assist in making preliminary judgments regarding risk classifications:

	Low Risk	**Moderate Risk**	**High Risk**
Consequences	Insignificant cost, schedule, or technical impact	Affects program objectives, cost, or schedule; however cost, schedule, performance are achievable	Significant impact, requiring reserve or alternate courses of action to recover
Probability of Occurrence	Little or no estimated likelihood	Probability sufficiently high to be of concern to management	High likelihood of occurrence
Extent of Demonstration	Full-scale, integrated technology has been demonstrated previously	Has been demonstrated but design changes, tests in relevant environments required	Significant design changes required in order to achieve required/desired results
Existence of Capability	Capability exists in known products; requires integration into new system	Capability exists, but not at performance levels required for new system	Capability does not currently exist

Also see Technology Readiness Levels matrix in Chapter 2

GLOSSARY

SYSTEMS ENGINEERING FUNDAMENTALS

AAAV Advanced Amphibious Assault Vehicle

ACAT Acquisition Category

ACR Alternative Concept Review

AMSDL Acquisition Management Systems Data List

ASR Alternative Systems Review

AUPP Average Unit Procurement Price

AWP Awaiting Parts

BL Baseline

BLRIP Beyond Low Rate Initial Production

C4ISR Command, ontrol, Communications, Computers, Intelligence, and Reconnaissance

CAD Computer-Aided Design

CAE Computer-Aided Engineering

CAIV Cost As an Independent Variable

CALS Continuous Acquisition and Life Cycle Support

CAM Computer-Aided Manufacturing

CASE Computer-Aided Systems Engineering

CATIA Computer-Aided Three-Dimensional Interactive Application

CCB Configuration Control Board

CCR Contract Change Request

CDR Critical Design Review

CDRL Contract Data Requirement List

CDS Concept Design Sheet

CE Concept Exploration

CEO Chief Executive Officer

CI Configuration Item

Circular A-109 Major Systems Acquisitions

CM Configuration Management

CM Control Manager

COTS Commercial Off-The-Shelf

CSCI Computer Software Configuration Item

CWI Continuous Wave Illumination

DAU Defense Acquisition University

DCMC Defense Contract Management Command

DDR Detail Design Review

DFARS Defense Supplement to the Federal Acquisition Regulation

DID Data Item Description

DoD Department of Defense

DoD 5000.2-R Mandatory Procedures for Major Defense Acquisition Programs (MDAPs), and Major Automated Information System Acquisition Programs (MAIS)

DoDISS DoD Index of Specifications and Standards

DSMC Defense Systems Management College

DT Developmental Testing

DTC Design To Cost

DT&E Developmental Test and Evaluation

EC Engineering Change

ECP Engineering Change Proposal

EDI Electronic Data Interchange

EIA Electronic Industries Alliance

EIA IS 632 Electronic Industries Association Interim Standard 632, on Systems Engineering

EIA IS-649 Electronic Industries Association Interim Standard 649, on Configuration Management

EOA Early Operational Assessments

FAR	Federal Acquisition Regulation
FCA	Functional Configuration Audit
FEO	Field Engineering Order
FFBD	Functional Flow Block Diagram
FIPS	Federal Information Processing Standard
FMECA	Failure Modes, Effects, and Criticality Analysis
FOT&E	Follow-On Operational Test and Evaluation
FQR	Formal Qualification Review
GFE	Government Furnished Equipment
GFM	Government Furnished Material
ICD	Interface Control Documentation
ICWG	Interface Control Working Group
IDE	Integrated Digital Environment
IDEF	Integration Definition Function
IDEF0	Integrated Definition for Function Modeling
IDEF1x	Integration Definition for Information Modeling
IEEE	Institute of Electrical and Electronics Engineers
IEEE/EIA 12207	IEEE/EIA Standard 12207, Software Life Cycle Processes
IEEE P1220	IEEE Draft Standard 1220, Application and Management of the Systems Engineering Process
IFB	Invitation for Bid
IIPT	Integrating Integrated Product Teams
IMS	Integrated Master Schedule
IOC	Initial Operational Capability
IOT&E	Initial Operational Test and Evaluation
IPPD	Integrated Product and Process Development
IPR	In-Progress/Process Review
IPT	Integrated Product Teams

JASSM Joint Air-to-Surface Standoff Missile

JROC Joint Requirements Oversight Council

JTA Joint Technical Architecture

KPPs Key Performance Parameters

LFT&E Live Fire Test and Evaluation

LRU Line-Replaceable Unit

LRIP Low Rate Initial Production

M&S Modeling and Stimulation

MAIS Major Automated Information System

MAISRC Major Automated Information Systems Review Council

MBTF Mean Time Between Failure

MDA Milestone Decision Authority

MDAP Major Defense Acquisition Program

MIL-HDBK-61 Military Handbook 61, on Configuration Management

MIL-HDBK-881 Military Handbook 881, on Work Breakdown Structure

MIL-STD 499A Military Standard 499A, on Engineering Management

MIL-STD-961D Military Standard 961D, on Standard Practice for Defense Specifications

MIL-STD 962 Military Standard 962, on Format and Content of Defense Standards

MIL-STD-973 Military Standard 973, on Configuration Management

MNS Mission Need Statement

MOE Measure of Effectiveness

MOP Measure of Performance

MOS Measure of Suitability

MRP II Manufacturing Resource Planning II

MS Milestone

MTTR Mean Time To Repair

NDI Non-Developmental Item

NIST National Institute of Standards and Technology

NRTS Not Repairable This Station

OA Operational Assessment

OIPT Overarching Integrated Product Teams

OMB Office of Management and Budget

OPS Operations

ORD Operational Requirements Document

OSD Office of the Secretary of Defense

OT&E Operational Test and Evaluation

P3I Preplanned Product Improvement

PAR Production Approval Reviews

PCA Physical Configuration Audit

PDR Preliminary Design Review

PDRR Program Definition and Risk Reduction

PEO Program Executive Office

PM Program Manager

PME Program/Project Manager – Electronics

PMO Program Management Office

PMT Program Management Team

PPBS Planning, Programming and Budgeting System

PRR Production Readiness Review

QA Quality Assurance

QFD Quality Function Deployment

R&D Research and Development

RAS Requirements Allocation Sheets

RCS Radar Cross Section

RDT&E Research, Development, Test and Evaluation

RFP Request for Proposal

S&T Science and Technology

SBA Simulation Based Acquisition

SBD Schematic Block Diagram

SD&E System Development and Demonstration

SDefR System Definition Review (as referred to in IEEE P1220)

SDR System Design Review

SE Systems Engineering

Section L Instructions to Offerors (Portion of Uniform Contract Format)

Section M Evaluation Criteria (Portion of Uniform Contract Format)

SEDS Systems Engineering Detail Schedule

SEMS Systems Engineering Master Schedule

SEP Systems Engineering Process

SFR System Functional Review

SI Software Item

SI&T System Integration and Test

SOO Statement of Objectives

SOW Statement of Work

SPEC Specification

SSA Source Selection Authority

SSAC Source Selection Advisory Council

SSEB Source Selection Evaluation Board

SSP Source Selection Plan

SSR Software Specification Review

SRR System Requirements Review

SRU Shop-Replaceable Unit

STD Standard

SVR System Verification Review

S/W Software

T&E Test and Evaluation

TDP Technical Data Package

TEMP Test and Evaluation Master Plan

TLS Timeline Analysis Sheet

TOC Team Operating Contract

TPM Technical Performance Measurement

TPWG Test Planning Work Group

TRR Test Readiness Review

VV&A Verfication, Validation, and Accreditation

WIPT Working-Level Integrated Product Team